CLASSROOM DEMONSTRATIONS OF WOOD PROPERTIES

U.S. Department of Agriculture
Forest Service
Forest Products Laboratory
PA–900

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Contents

Preface

Teachers often ask, "Are there no simple demonstrations I can use to show how a familiar material such as wood behaves? And, better still, aren't there ways of showing why?" To answer these many requests, the demonstrations here have been selected to show some of the properties of wood and how these properties relate to the cellular structure of wood. This manual starts with some experiments using woody plants, follows with illustrations of wood anatomy, and finally illustrates the effect of anatomy on performance. Most of the demonstrations are quite simple, requiring little or no special apparatus, and may be used in lower grades. A few are more elaborate and need equipment normally found in a botany laboratory.

The intent is not to provide a course of study, but rather to present a collection of demonstrations which can be used in series, or individually, to illustrate a particular lesson. Several of the studies can be expanded to meet the needs of older pupils, or where suitable equipment is available. Without doubt, many of the demonstrations can be improved, and there is little reason why new studies in this area should not be devised by the thoughtful teacher or the imaginative student working on a science project.

The Forest Products Laboratory of the Forest Service, U.S. Department of Agriculture, which prepared this manual, greatly appreciates the willingness of the following instructors and authors to permit their work to be included: P. B. Kaufman, Department of Botany, University of Michigan, Ann Arbor, Mich.; R. W. Kennedy, Canadian Forest Products Laboratory, Vancouver, B.C.; J. L. Farrer, Department of Botany, University of Toronto, Toronto, Ont.; and D. C. McIntosh, The Mead Corp., Chillicothe, Ohio.

A WORD ABOUT WOOD

Wood is so commonplace that we take it for granted. Yet that solid chunk of wood becomes an intricate arrangement of strong, though tiny, cells when seen under a microscope. If we trim the surface of a piece of wood with a sharp knife and look at it under a 10× hand lens, we can begin to see this cellular network.

The majority of wood cells are long and thin with tapered ends, rather like hollow toothpicks. When we say that they are long, however, we mean only that they are much longer than they are wide. For example, cells from white pine wood are about 4 millimeters long, which is a little taller than this capital *I*. Most of the cells are this shape, and have their long dimension nearly parallel to the long direction of the tree stem. Whether we see the large or small dimension of the cell depends on how the wood is cut.

Generally, woods are divided into two groups, **softwoods** and **hardwoods,** depending on the type of tree. The softwoods consist of the cone-bearing trees, which have needles or scalelike leaves, such as the pines, spruces, and firs. The other group, called hardwoods, consists of broadleaved trees which usually drop their leaves in the fall. These include the oaks, ashes, birches, maples, and other contributors to the fall colors. The separation into these two groups does not mean that all the hardwoods have harder wood than the softwoods, but it is a convenient way to divide woods based on their structure.

Softwood

The arrangement of cells in a piece of softwood is shown in figure 1. We speak of three faces of wood, namely the **cross-sectional** (1), **radial** (2), and **tangential** (3). The cross-sectional face is the surface we see if we cut across a tree stem, or when we look down at a tree stump.

Growth Rings

It is on the cross-sectional face that the growth rings, or annual rings (4), are most easily seen. A growth ring is the layer of wood formed around the stem in a single year. Each year the tree trunk grows in width by producing a new layer of wood cells just below the bark. At the same time, the covering bark expands to accommodate the new wood by the addition of new bark cells. Both wood and bark are produced from a layer of living cells, called the **cambium,** between the wood and bark.

Earlywood and Latewood Cells

Cells formed in the spring and early summer are wider in the radial direction, thinner walled, and shorter than those produced later in summer. The thin-walled cells comprise the earlywood (5) and the thicker walled ones latewood (6). Each growth ring consists of both earlywood and latewood. Thus, on looking at a cross section one can see the alternate rows of light-colored earlywood and darker latewood. By counting the number of bands of earlywood between the pith, which is in the very center of the stem, and the bark, we can tell the age of the tree at that particular height. Almost all the upright cells in softwoods are relatively long with pointed ends. These are called **tracheids** and support the tree in addition to providing a passage for liquids to move from the roots to the crown.

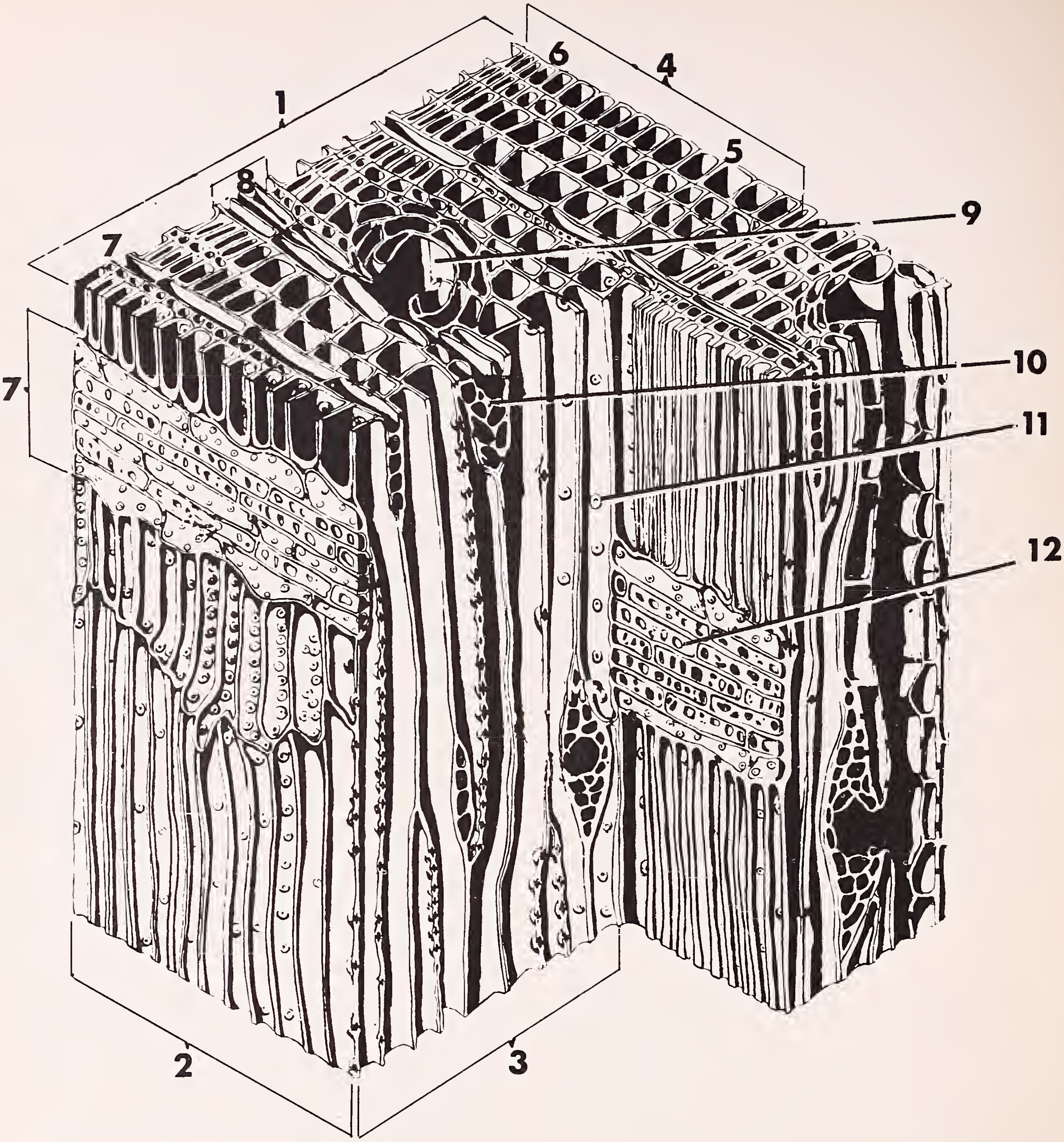
Wood Rays

The bottom left of figure 1 is marked (2), indicating the radial face. This is what we would see if we cut the stem along a radius from the pith to the bark. On this face the rays (7), where food is stored and distributed radially in the stem, are most clearly visible. The ray cells have their long dimension lying horizontally in the tree. Rays are several cells deep and may be one to several cells wide. A ray may consist only of ray cells (7) or it may contain a horizontal resin duct running along the center. This is called a fusiform ray (8).

On the third face, the tangential (3), the end view of the rays can be seen, and it is on this face that it is easiest to tell whether they are simple or fusiform.

Pits

Solutions pass from cell to cell through small openings in the cell wall called pits. As the cell walls in two adjacent cells develop, small circular depressions are left in the thickening secondary wall. Usually the depressions occur opposite each other in adjoining cells, so that a



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Softwood Key—

1. CROSS-SECTIONAL FACE
2. RADIAL FACE
3. TANGENTIAL FACE
4. ANNUAL RING
5. EARLYWOOD
6. LATEWOOD
7. WOOD RAY
8. FUSIFORM RAY
9. VERTICAL RESIN DUCT
10. HORIZONTAL RESIN DUCT
11. BORDERED PIT
12. SIMPLE PIT

Figure 1.—Wood structure of a softwood.

pair of pits forms with only the pit membrane, composed of the two primary walls and the inter-cellular layer, between the two pit cavities as illustrated in figure 2. The two pits are sometimes referred to as a pit pair, but usually the term pit is applied to the openings in the two cell walls. The pit membrane acts as a filter and also as part of the supporting wall.

The three main types of pits, called **bordered, simple,** and **half-bordered,** are shown diagrammatically in cross section (fig. 2). The pit between two ordinary support cells, or tracheids, has an overhanging border, hence the name bordered pit (2A). The opening between two ray cells has no border, and is called a simple pit (2B). As one might expect, the pit between a tracheid and a ray cell has a border on the tracheid side but none on the ray side. Thus it is half-bordered (2C). In bordered and half-bordered pits of softwoods, the pit membrane has a circular thickening in the center, called the **torus.** If this is pushed against the pit border it forms an effective seal against the movement of liquids through the pit.

In the softwood block diagram, figure 1, a bordered and a simple pit are shown, (11) and (12) respectively.

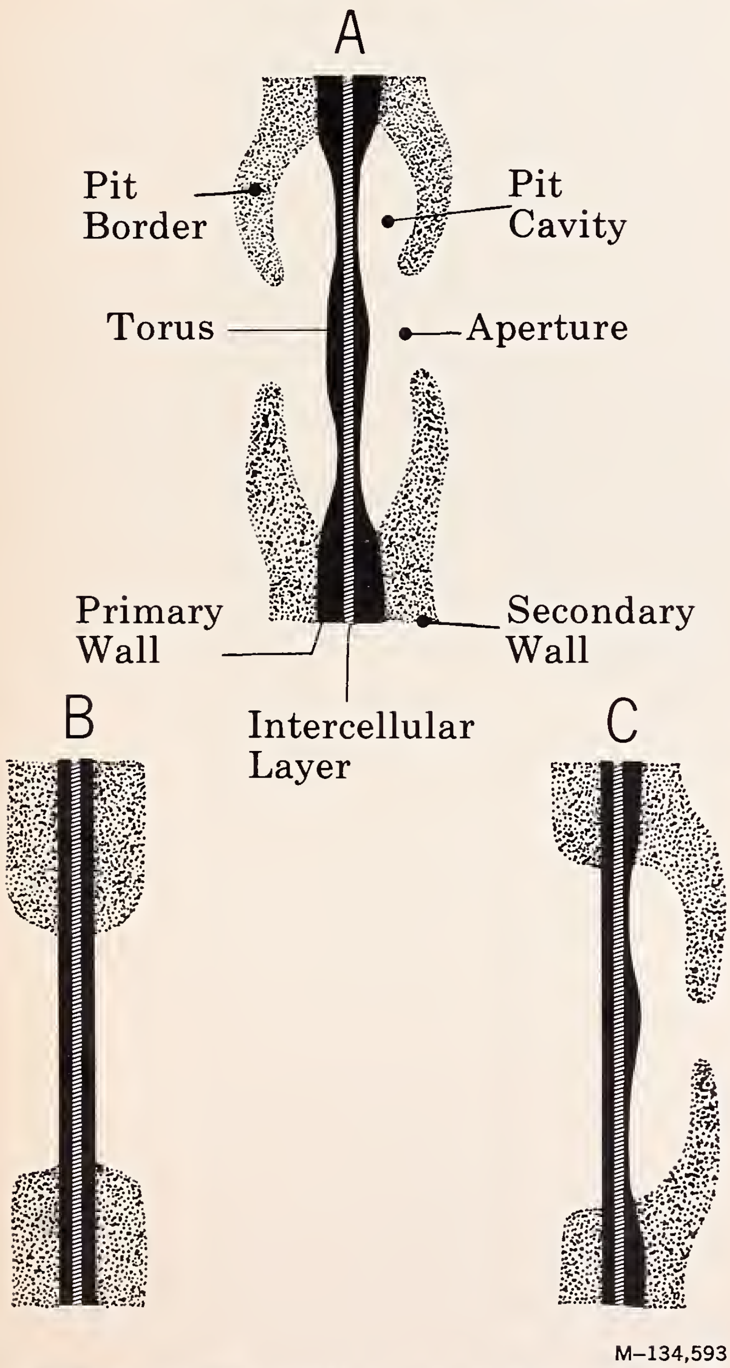


Figure 2.—Cross sections of: A, a bordered pit; B, simple pit; and C, a half-bordered pit.

Resin Ducts

Resin ducts may run up and down, figure 1, (9), or horizontally (10) in a stem. A resin duct is formed by a space between several cells expanding to form a large opening in the wood. As would be expected from the name, these ducts are usually full of sticky resin, which is released from the cells lining the opening, or duct.

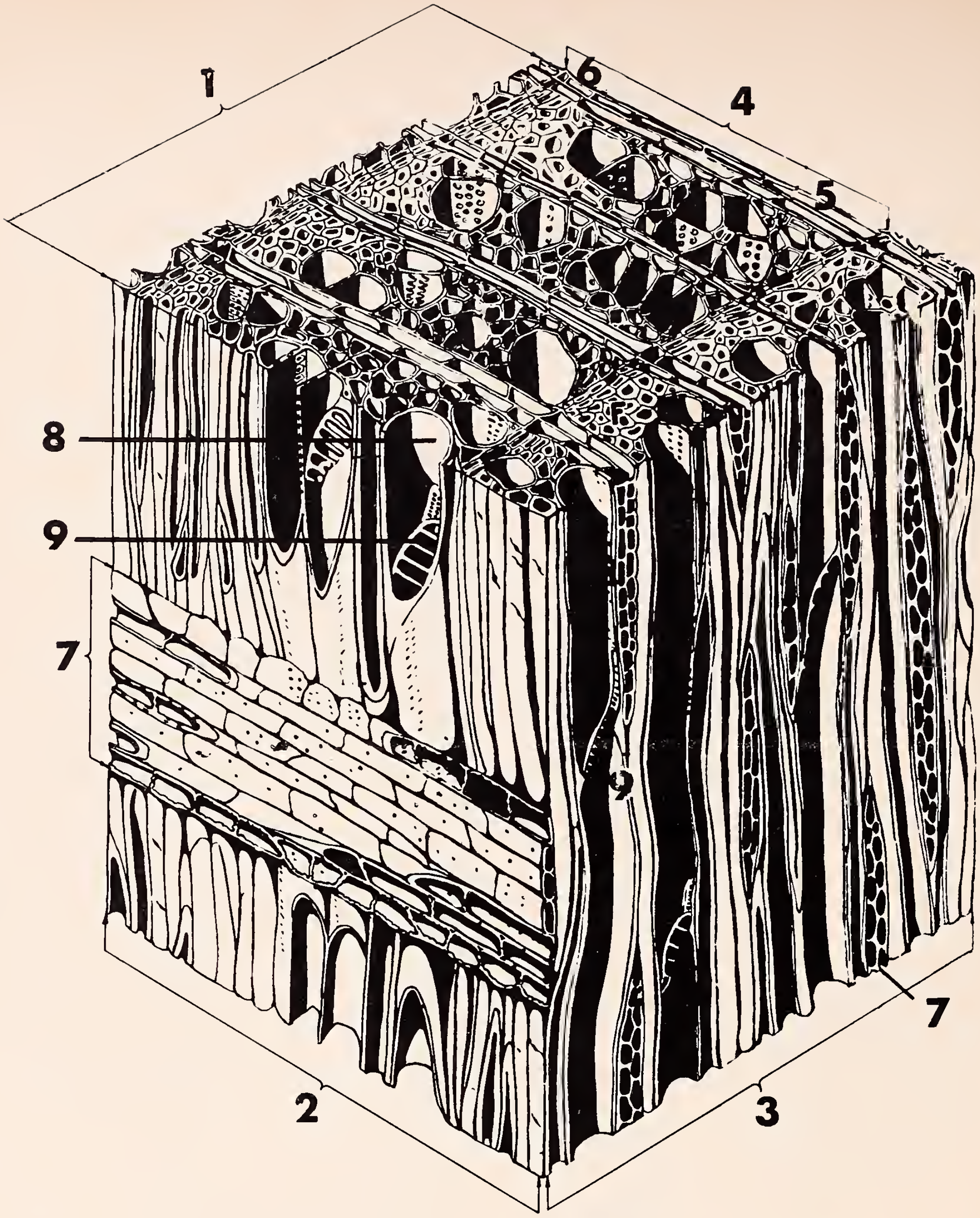
Hardwood

When we look at the hardwood block, figure 3, we can see both similarities to, and differences from, the softwood. There are the same three faces and the general structure is similar, with the long dimension of most of the cells parallel to the length of the tree. However, we find a greater variety of cells in a hardwood than in a softwood, and the cells are not arranged in the orderly radial rows found in the softwood, see figure 1.

In figure 3 the radial face (2) allows us to see the side view of the ray (7), while on the tangential face (3) the ends of the rays are visible. The hardwood rays may be from one to many cells wide, and seldom contain resin ducts as are found in the softwoods.

Vessels

In the diagram of the hardwood block, figure 3, some rather large cells called vessel segments (8) can be seen. Unlike the resin ducts in softwoods, each vessel segment develops from a single cell. The segments are joined end to end in the stem, like a series of drainpipes, the long tubes they form serving as the main passages for liquid moving from the roots to the crown of the tree.



Hardwood Key—
1. CROSS-SECTIONAL FACE
2. RADIAL FACE
3. TANGENTIAL FACE
4. ANNUAL RING
5. EARLYWOOD
6. LATEWOOD
7. WOOD RAY
8. VESSEL
9. PERFORATION PLATE

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Figure 3.—Wood structure of a hardwood.

At the end of each vessel segment there is a small grill, called a **perforation plate** (9), visible here on the radial face. The arrangement of the openings in the grill is different for each species of tree. The remainder of the wood is made up mainly of **fibers,** which are cells similar to softwood tracheids, and **parenchyma** cells containing food material.

Between vessels the pits usually are bordered, as are those between vessels and fibers. Pits between vessels or fibers and ray cells are simple on the ray cell side and usually bordered on the other.

Ring-Porous and Diffuse-Porous

In the hardwood shown (yellow-poplar) in vessels are about the same diameter both in the earlywood (5) and in the latewood (6). When the vessels are almost the same width throughout, the wood is called diffuse-porous because the vessels are scattered (diffused) throughout the entire annual ring.

Other hardwoods, oaks for example, have much wider vessel segments in the earlywood than in the latewood. These hardwoods are called ring-porous because, on looking at a stem cross section, the wide vessels or pores appear as rings, with intervening bands of wood between them having smaller vessels.

Sapwood and Heartwood

Sapwood is made up of the outermost growth rings in the stem, those lying just under the cambium and bark. One cannot give a precise figure for the width of this zone as it varies from species to species, from tree to tree, and even within a single tree. In the sapwood many of the cells are still living, containing starch and sugars, and it is through this wood that water and nutrients flow from the roots to the leaves. The wood generally is lighter in color than the heartwood, and less resistant to decay and insect attack.

While sapwood is present in all trees, not all species have a definite heartwood zone. Near the center of the stem, as a tree grows older, the water content of the wood gradually decreases, there is a reduction in the amount of stored food material, and **resins, gums,** and **tannins** accumulate. This zone, which progressively increases in area, is referred to as the heartwood, and differs from sapwood particularly in its chemical composition. Typically the heartwood is darker in color than the sapwood, as in black walnut.

Physical changes in the cells during heartwood formation may include the torus being pressed against the pit border, blocking the pit aperture. Or **tyloses** may develop, where a parenchyma cell expands into, and fills, the cell cavity of an adjoining, nonparenchyma cell. The chemical and physical changes do not reduce the strength of the wood, but make it more resistant to decay and insect attack. Thus while the outer ring of sapwood both supports the tree and serves as a storage area and passage for nutrients and water, the heartwood is dead tissue serving simply as a support. Heartwood may be found in both softwood and hardwood species.

The Woody Cell

When we talk of cells in wood our main concern is with the **cell wall.** This cell casing determines the size and shape of the cell. Almost all of the cells in the wood we used were no longer living, that is, did not contain living protoplasm, when the tree was felled. To be sure, there was the living cambium layer, and the few cells just inside it which are always alive in the tree stem. In addition, there were storage cells, called parenchyma, both in the rays and arranged vertically in the stem. These retain sugar and starch after the surrounding, supporting tracheids (the long, pointed cells), and vessels (the wide, conducting cells) have lost their protoplasm and become a passage for liquids to pass up the stem. Thus for the most part, we are concerned not with living cell contents, but rather with the walls of the cells that make up the wood.

Lignin

If we look at a tracheid under a high-powered microscope, the wall appears as a series of layers. This is shown in the diagram in figure 4. The intercellular layer, which lies between the cells and serves to hold them together, consists largely of lignin. The composition of lignin is not fully known, but it serves to stiffen the plant stem. As we can see from figures 1 and 3, the cells overlap each other for part of their length, and, bound together, form the solid substance of wood. In papermaking, the intercellular substance may be dissolved away to free the separate fibers, which can then be made into a sheet.

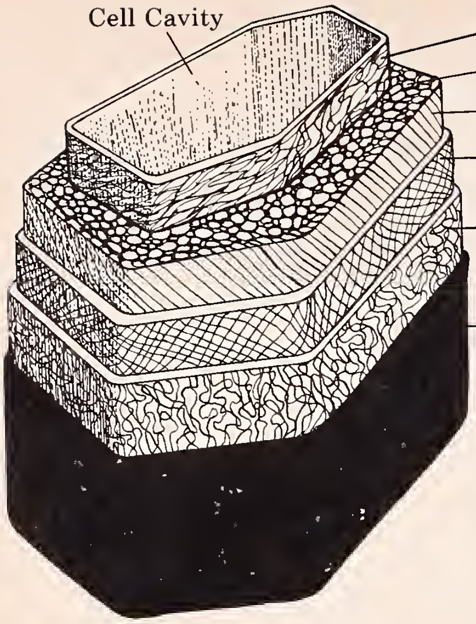

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Figure 4.—Cross section of a woody cell showing the several layers in the cell wall.

Arrangement of Cellulose in the Cell Wall

The cell wall consists mainly of **cellulose** arranged in long threadlike chains, and interspersed with **lignin,** and **hemicelluloses.** Wood contains 40 to 55 percent cellulose, 15 to 25 percent hemicellulose, 15 to 30 percent lignin, and 2 to 15 percent other substances called extractives. The long cellulose molecules are grouped together in strands, which in turn form thicker, ropelike structures called fibrils. The arrangement of the fibrils is indicated in figure 4. In the primary wall they form a loose irregular net, then on passing into the first layer of the secondary wall, S_1, the network becomes more precise. By the time the S_2 layer of the secondary layer is reached, the fibrils run almost parallel to each other in a spiral around the cells. This layer is the thickest of the several in the cell wall and has the greatest effect on how the cell behaves. The smaller the angle which the fibrils make with the long direction of the cell, the stronger is the cell. Finally, in the innermost layer of the cell wall, S_3, the fibrils are once again in a netlike arrangement.

While the cellulose gives flexibility to the cell wall, it is the lignin which makes the cell walls rigid. Lignin does not have a fibrous structure but, forming round the fibrils, gives a wall constructed like reinforced concrete.

Extractives

Extractives form only a small part of the cell wall, but can be quite important. In many species the color or smell of the wood is due to extractives, some examples of which are **lignans, tannins, terpenes,** and **polyphenols.** Woods resistant to decay, such as black walnut or redwood, usually have a high extractive content, while some species will corrode metal when the two are in contact for a long time.

These substances are called extractives because they can be removed, or extracted, from the wood by heating it in water, alcohol, or various other chemicals.

Inorganic Constituents

The various salts comprising the inorganic constituents of North American woods amount to between 0.2 and 0.9 percent by weight. The main elements present are **calcium, magnesium, potassium,** and **sodium,** together with lesser quantities of other elements, for example, boron, copper, iron, and manganese. These substances occur as carbonates, phosphates, silicates, and sulphates, and are distributed throughout all layers of the cell wall. The inorganic constituents make up the ash when wood is burned.

Examining Wood Structure

Whether it is more desirable to provide the student with slide material already prepared or to have the student himself cut the tissue depends mainly on the amount of time and the facilities available. If there is time to teach the student how to make at least passable sections, this is desirable. However, if the student is unlikely ever again to require this aptitude, it would be better to provide prepared slides, as the making of good microtome sections usually does not come quickly. This takes much less class time, and the student is more likely to see clearly the features under discussion. A compromise might be to demonstrate how the sections are made, then conduct the studies using prepared slides.

Macerations, in which the wood has been divided into single, whole cells by dissolving the bonding middle lamella, are useful to illustrate the different shapes and sizes of individual cells. A simple maceration technique is described on page 16. Macerated tissue can be kept on hand

and students allowed to prepare temporary slides with glycerine, applying stain themselves.

Instructions on making sections and macerations are given in such books as D. A. Johansen's "Plant Microtechnique," 1950, McGraw-Hill Book Company, Inc., New York; and J. E. Sass' "Botanical Microtechnique," 1958, Iowa State College Press, Ames. Excellent, concise instructions are to be found in "The Preparation of Wood for Microscopic Examination," Forest Products Research Leaflet No. 40, 1968, available from Her Majesty's Stationery Office, London, Great Britain.

For general information on wood structure and properties, see Panshin, de Zeeuw, and Brown, "Textbook of Wood Technology," Vol. 1, McGraw-Hill Book Company, 1964; or "The Structure of Wood," by F. W. Jane, A & C Black Ltd., 1956.

WOOD IN PLANTS

Experiment 1—The Growth Sheath Idea

Objective

To show how wood layers are laid down in the tree.

Material

Small conifer stem, a discarded Christmas tree for example. Growth sheaths in a tree stem are diagramed in figure 5.

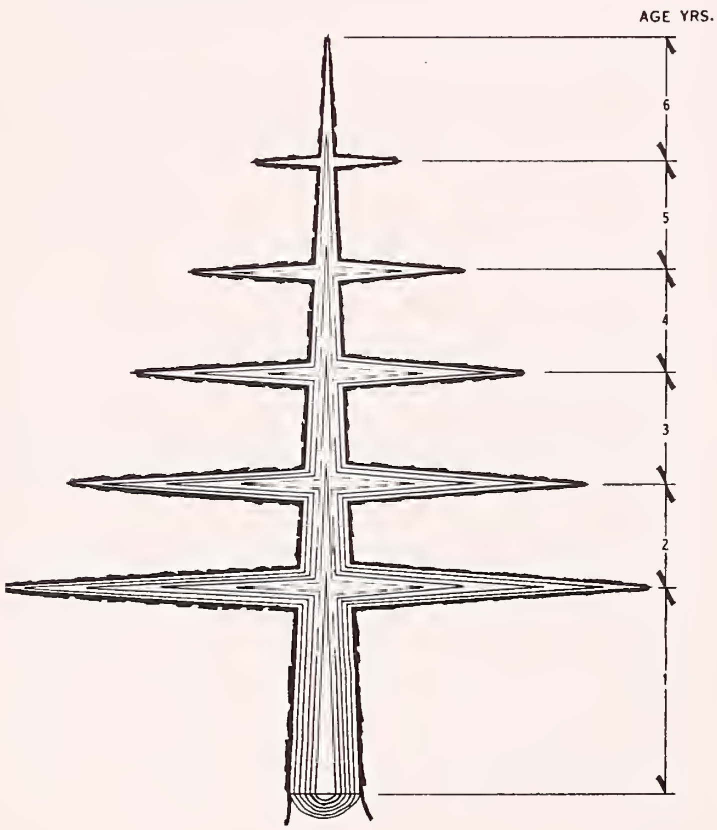

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Figure 5.—Diagram of a tree stem cut away to the center, exposing the growth sheaths. The top of each sheath shows the height of the tree at the end of a given growing season.

Method

Carefully saw the tree stem vertically down the center exposing the pith. It may be desirable to saw to one side of the pith, then trim to the center. If desired, one or two side branches can be treated in the same way. Needles can be fixed on the untrimmed branches by spraying with a clear lacquer.

The exposed stem can be used to demonstrate the pattern of the annual growth sheaths shown in figure 5. A growth sheath is the cone of new wood which the tree produces each year as it increases in height and width.

Observation

Using the model and diagram, one can illustrate:

1. How the tree increases each year in height and diameter.
2. How branches form in the stem.
3. How the age of a tree can be told from the number of rings: The true age can be found only by counting rings at ground level, because the number of rings decreases with height in the stem (fig. 5).

Application

1. The shape of the tree and its taper affect sawing. Thus in sawing a tree with a highly tapered stem, if the saw is parallel to the bark, straight-grained lumber results, because the saw follows the growth sheath. If the saw is parallel to the pith, the lumber has sloping grain because the saw moves obliquely across the growth sheaths.
2. The growth of branches results in knots in the lumber. For clear lumber it is desirable to have as few branches as possible while still getting good growth.

Experiment 2—Where Water Moves in Plants

Objective

To show the principal path of water transport in actively growing woody plants.

Material

Woody plants, sharp knives, razor blades, scalpels, two-hole rubber stoppers, medium-sized bottles, ring stands with burette clamps, capillary tubing, rubber bands, pails of water (one per table).

Methods

The shoots to be used are plunged into water immediately after cutting, and 6 to 7 centimeters of stem removed from the base of each shoot while it is submerged. All cutting operations must be carried out under water. Prepare the stem bases by the two methods described below using sharp knives and razor blades. Two shoots are used for each method.

Method 1.—Make longitudinal slits, about 3 centimeters long and 1 centimeter wide, at the base of shoots in the bark only. Peel back these bark strips carefully, without tearing them from the stem at the top of the slits (fig. 6). Now a cylinder of wood is exposed. Remove this cylinder carefully by cutting out with a sharp knife or scalpel. The strips of bark must remain intact.

Method 2.—Do the same as in Method 1 except leave the wood cylinder intact and tie back the bark strips to the portion of the stem not cut, just above the slits. A rubber band is a convenient way to hold the bark in place (fig. 6).

General.—Fit two-hole stoppers into four medium-sized bottles, with a glass tube in one hole of each stopper to allow free entry of air. The other side of the stopper should be cut longitudinally into the hole, so that a stem can be inserted (fig. 7). Add 500 milliliters of water to each bottle, and weigh the bottle plus water, but without the stopper, to the nearest 1.0 gram.

Experiment 2.—Continued on p. 30

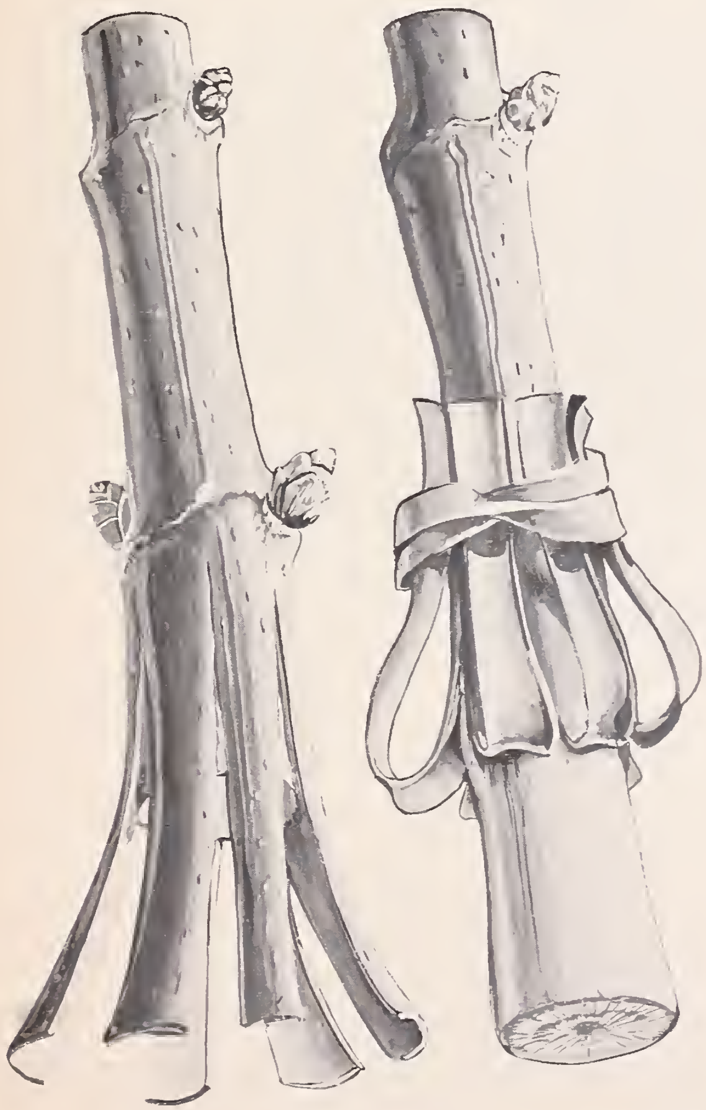

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Figure 6.—The shoot at left was prepared by method 1, while that at right by method 2.

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Figure 7.—A shoot in place and a capillary tube to allow air entry.

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Experiment 3—How Water Moves in Plants

Objective

To show water tension and movement of dye in woody plant shoots.

Material

Woody plants in pots, light source, fan, eosin (bluish) solution at 1.0 and 0.1 percent concentrations, large glass jars, graduated cylinder, sharp knife, ring stands, clamps, and clay.

Demonstration of Water Tension

Method.—Take two plants and place them about 2 feet in front of the fan and lamp. About 5 centimeters from the base of each shoot, carefully cut out an area of bark about 1 centimeter wide and 3 centimeters long, avoiding any injury to the wood (fig. 8). In the center of the debarked area make a cuplike dam with plastic clay. Into this cup pour 0.1 percent eosin solution from a graduated cylinder being careful not to spill any over the dam. Record the amount poured into the cup and mark the level on the clay.

Now with a sharp knife or scalpel, make a horizontal cut into the wood below the surface of the eosin solution in the cup. Keep the plant in front of the fan and light.

Observation.—Observe the results carefully. Note the drop in the level of the eosin solution and record the total volume remaining in the cup at the end of 2 hours. Cut the stem transversely and note the pathway of the eosin above and below the point of entry.

If convenient, this may be tried on an intact tree in the field in addition to the laboratory experiment.

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Figure 8.—Demonstration of water tension showing the position of the clay cup on the stem and, enlarged, the cuts in the stem.

Movement of Dyes in Woody Plant Shoots

Method.—Take two plants of the same genus as used above, remove them from the pots, wash the root systems carefully, and place the plants in a jar of tap water until needed. Place a beaker containing 500 milliliters of 1.0 percent eosin solution on the base of a ring stand fitted with two burette clamps (fig. 9). Cut halfway through one stem about midway up the shoot. Do not cut the other. Place the plant root systems in the eosin solution and suspend the plants by clamping the stems halfway up the shoots. Place the lamp about 1 foot over the setup and turn on the fan about 2 feet from the apparatus.

Observation.—After 2 hours, dismantle the apparatus. Trace the path of the eosin in the roots and stems by cutting them transversely and looking at the surfaces under a hand lens or dissecting microscope. It is assumed that the xylem sap in transpiring trees is in a state of tension. This can be illustrated by the upward movement of the dye in the plant.

Note: This study is based on material in a Botany Laboratory Manual by permission of P. B. Kaufman, Department of Botany, University of Michigan, Ann Arbor, Mich.

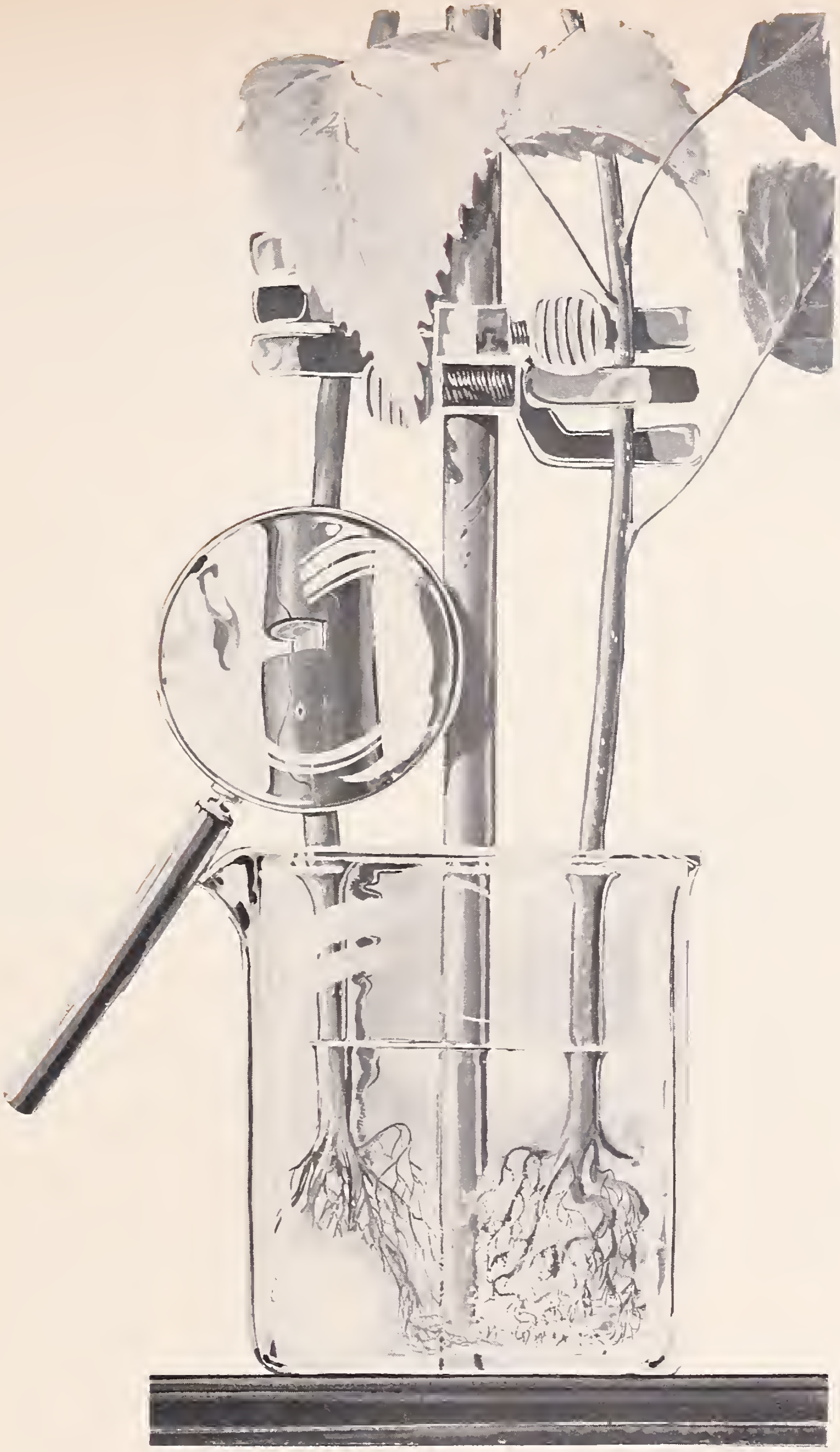

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Figure 9.—The plants suspended with roots in the beaker are used to trace the movement of the dye absorbed by the roots. The cut to be made in the stem is seen through the magnifying glass.

Experiment 4—Size of Openings Between Cells

Objective

To show the relative size of conducting elements in woody plants.

Material

Three small-size funnels, two ring stands and six clamps, rubber tubing to fit plant stems, copper wire, 1 percent aqueous eosin solution, India ink, mercury, scalpel, 125-milliliter beaker, and straight, unbranched plant stems from a variety of species.

Method

Take an unbranched stem section about 3/8 inch thick and 8 inches long. Make a transverse cut at the base of the stem and fit it snugly into a 6-inch piece of rubber tubing. Tie the tubing in place with copper wire, but not too tightly. Fix the other end of the rubber tubing to the stem of a small pyrex funnel. Tie the tubing to the funnel stem as mentioned above. Suspend the apparatus in a small ring or burette clamp on a ring stand as in figure 10.

Prepare three stem sections in this way. All may be attached to the same ring stand. Place a 125-milliliter beaker under each stem. Fill each tube and funnel with a different solution: mercury, India ink, and 1 percent eosin. Be especially careful not to spill any mercury. Add the liquid slowly when filling the funnels. To displace the air trapped in the tubing, alternately squeeze and release the tubing with the fingers.

Observation

After the liquid is put in the funnel, note how much time elapses until it first appears at the bottom of the stems. Measure the amount of each liquid in the beakers at the end of 1, 2, and 3 hours. Compare the results for the various species used by the different groups in the class. The large vessels in the hardwoods allow passage of larger particles than can pass through the pits in softwood cells.

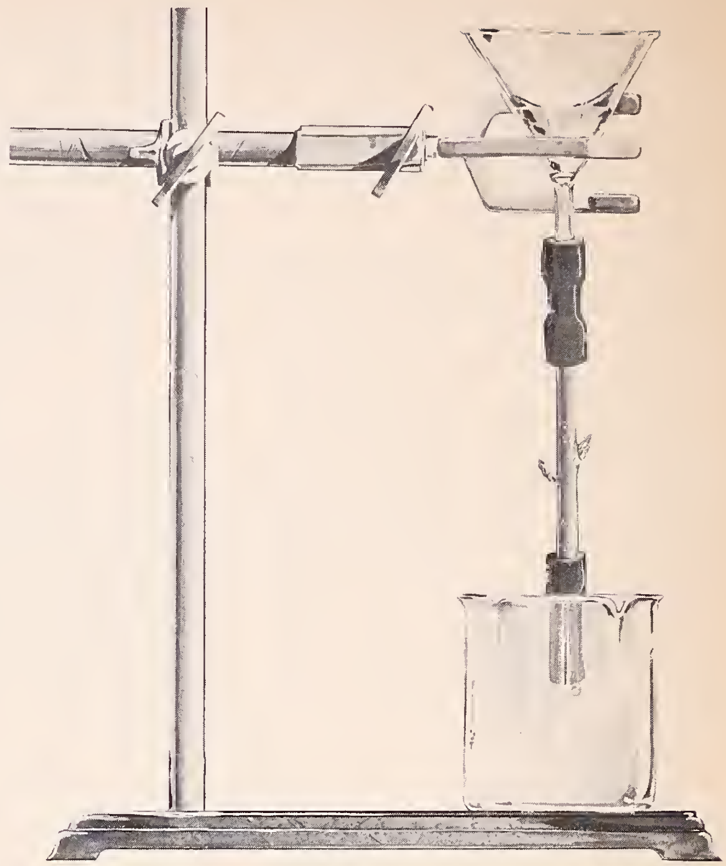

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Figure 10.—Setup for demonstration on conducting elements in woody plants. Three such setups are necessary; one each for eosin, India ink, and mercury.

Most of the water movement in plants takes place through the vessels and tracheids. The vessel segments are arranged end to end, with pits on the side walls, but with relatively large openings at the top and bottom of each segment. In contrast, the fibers overlap at the ends and solutions must pass through the pits, which are much smaller than the openings in the perforation plates of the vessels.

Note: **This study is based on material in a Botany Laboratory Manual by permission of P. B. Kaufman, Department of Botany, University of Michigan, Ann Arbor, Mich.**

Experiment 5—What Happens Inside a Leaning Softwood Tree

Objective

To illustrate formation of compression wood in conifer stems.

Material

Individually potted, actively growing, coniferous seedlings, about 3 to 6 months old, which have not set buds; for example, Douglas-fir, red pine, or slash pine. Greenhouse space, sectioning and staining material.

Method

Separate the potted trees into two groups. Allow one group to stand in the normal upright position for the whole experiment.

For the remainder, tilt plants and pots at about 60° to the vertical. After 5 days, stand them upright. When they have been upright for another 5 days, tilt again for another 5 days, making sure that the same side of the plant is down. Then place in an upright position for 2 weeks before harvesting.

Take 1-inch-long portions of both groups of stems, make cross sections, stain with safranin-fast green, and view under a microscope.

Observation

The untilted plants will show regular growth, with little difference between the cells. The tilted plants will show two bands of atypical cells on the lower side of the stems, representing cells which completed part of their differentiation while the plants were tilted. Compare this wood with that seen in "Compression Wood in Softwoods," experiment 9.

Application

Compression wood is commonly found on the lower side of branches and leaning softwood stems, or on the lee side of stems exposed to strong prevailing winds. It has different strength properties than normal wood.

Note: This study is based on work reported by R. W. Kennedy and J. L. Farrer in the section, "Tracheid Development in Tilted Seedlings," of the book, "Cellular Ultrastructure of Woody Plants," pages 419 to 453, Syracuse University Press, 1965.

WOOD ANATOMY

Experiment 6—The Three Faces of Wood

Objective

To show those differences which are visible without a microscope among the cross-sectional, radial, and tangential faces of wood.

Material

Section of oak stem with bark attached, about 8 inches in diameter and the same in length. While other species can be used, oak is particularly desirable because it has definite growth rings and very large, readily visible rays.

Method

Saw and sand the section to expose the cross-sectional, radial, and tangential faces, as shown in figure 11. Brush off the surface to clear the pores after sanding, and finish with clear lacquer. This accentuates the wood characteristics.

Observation

On the block cross section:

1. Note the arrangement of the growth rings.
2. Note the distribution of cells in the growth rings, with larger vessels in early part of the growth rings.

On the block radial section:

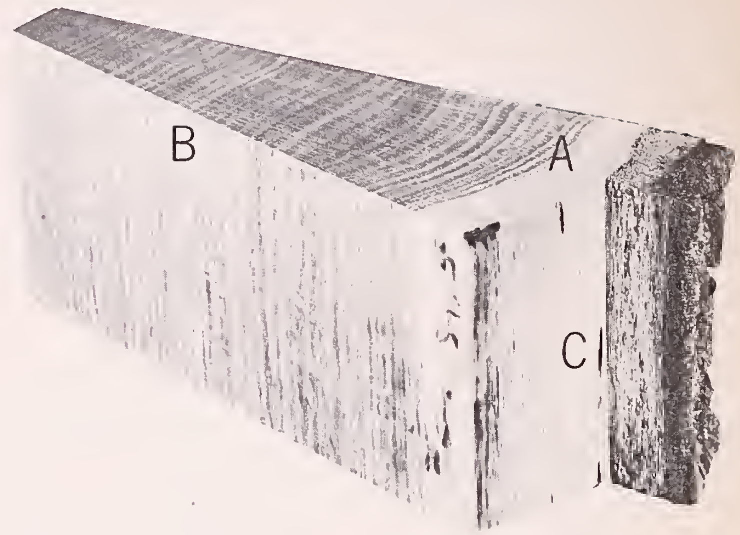
1. The large rays running out from the pith to the bark transport food material radially in the stem and create a distinctive figure in sawn lumber.
2. Note the large tubes of vessels arranged vertically in the stem.

On the block tangential section:

1. The rays are seen in end view, therefore the cross sections of ray cells and the long dimension of other cells are exposed.

Application

If a block is available with wide and narrow growth rings, this can be used to show how narrow growth rings have a greater proportion of vessels than wide rings. In machining oak, slow-grown wood with narrow growth rings is easier to machine, as much of ring is air. Fast-grown oak is stronger and heavier, as each growth ring has a greater proportion of small, thicker-walled cells.



M–134,590

Figure 11.—Block of oak cut to show: A, the cross-sectional, B, radial, and C, tangential faces.

Additional Species

Similar blocks may be prepared for contrasting woods:

- aspen—has a variety of cells, but vessels are smaller than oak, rays much smaller than oak, and the vessels are spread relatively uniformly throughout the rings.
- California red fir—has large rays, no resin ducts, relatively uniform cell structure, and very little latewood.
- loblolly pine—has small rays, resin ducts, and uniform wood structure with pronounced latewood.

Alternative Species

Depending on location it may be easier to obtain wood specimens of species other than those referred to above. The following alternate species have characteristics similar to, though not identical with, those woods already mentioned:

- white oak: honey locust, Oregon white oak.
- aspen: cottonwood, willow.
- California red fir: balsam fir, eastern hemlock.
- loblolly pine: Douglas-fir, red pine.

Experiment 7—Why Woods Have Different Properties

Objective

To show differences in wood anatomy among species.

Material

Small blocks of oak, aspen, California red fir, and loblolly pine. Sectioning and staining material.

Method

Prepare slides of transverse, radial, and tangential sections according to instructions in texts such as those suggested on page 7. View the slides under the microscope.

Observations

In this study the differences in cell size and arrangement can be illustrated at the microscopic level. If slides are not readily available, the photomicrographs at the end of the manual can be used to show the differences in anatomy.

Application

Cell variability in oak gives it variety in grain. Aspen, on the other hand, is a relatively uniform wood, and is easier to work than oak. Similar differences exist between loblolly pine and California red fir. The greater number of thick-walled cells in the loblolly pine growth ring give it strength, hence it is often used in construction. Conversely, the relatively few latewood cells in red fir make it ideal for millwork, as it is composed almost entirely of thin-walled cells which can be machined easily.

Some examples of differences to look for are given below:

Oak	*Aspen*	*Red fir*	*Loblolly pine*
Vessels much larger in early part of ring.	Vessels relatively uniform throughout ring.	Vessels absent	Vessels absent.
Rays one to many cells wide	Rays one cell wide	Rays one or two cells wide	Rays one cell wide, except when containing a resin duct.
Growth rings conspicuous	Growth rings inconspicuous	Narrow latewood band	Broad latewood band.
Resin ducts absent	Resin ducts absent	Resin ducts usually absent	Many resin ducts.

Experiment 8—What a Single Wood Cell Looks Like

Objective

To show differences in wood cell shapes and sizes.

Material

Small specimens of softwood and hardwood.

Method

Split off small toothpick-size slivers of wood from a ½-inch-long block. If pieces are split off along the grain, more cells will remain whole than by cutting. Place several pieces in a test tube and cover with strong household bleach. Cork the tube and place in an oven at 50° C. for 24 hours.

Remove the tube from oven and stir the contents with a glass rod; then the wood should break into individual cells. If separation is not complete, allow it to cook a little longer.

When separation is satisfactory, allow the cells to settle to bottom of test tube, pour off the bleach or remove with an eye dropper, and add distilled water to wash the cells. Repeat washing two or three times.

It may be desirable for the instructor to do the maceration prior to the class and issue macerated material to the students.

The cells may be stained for better viewing by adding a few drops of safranin to the last wash.

Small amounts of the macerated material are put on glass slides with an eye dropper, a drop of glycerin is added, and a cover slip placed on top. This temporary mount can be viewed under the microscope.

Observation

1. In softwoods:
   a. The cells are relatively uniform in type and shape.
   b. The ray cells are much different from the upright cells.
2. In hardwoods:
   a. There is considerable variety in cell type and size; for example, vessel segments, fibers.
   b. Note the brick-shaped cells, parenchyma, which are rather similar in shape to ray cells.
   c. Note the differences among hardwoods, especially in vessel segment size and in the perforation plate.

Application

Long fibers in conifers make these species desirable for paper, especially where strength is needed. Shorter, flatter cells from hardwoods are good for writing papers where a smooth surface is more necessary than strength.

Experiment 9—Compression Wood in Softwoods

Objective

To show the difference in anatomy between compression wood and normal wood in conifers.

Material

A stem disk of any softwood with pronounced compression wood. Softwood samples, some with compression wood and some without.

Method

The disk is used to illustrate the occurrence of compression wood in the stem and the difference in gross appearance between it and normal wood (fig. 12). Make cross section slides of both normal and compression wood. Stain both types of slides with safranin-fast green for the same period of time, examine them under the microscope, and compare their appearance.

Observation

Note that in compression wood the growth rings are wider than normal, while the cells have thicker walls and are more rounded in outline than normal cells. There are spaces between the corners of the compression wood cells, but not between normal cells. It may be possible to show the difference in lignin content with different intensity of staining if safranin alone is used, but this is rather doubtful. Compression wood is always formed on the downward side of leaning softwood stems. It does not occur in hardwoods.

M–28,425F

Figure 12.—Stem cross section of softwood with compression wood where the growth rings are wider and darker, within the rectangle.

Application

Compression wood cells are thicker walled and harder to machine than normal cells. The greater amount of lignin present reduces the suitability of compression wood for pulping. Compression wood shrinks more along the grain than does normal wood, causing problems when both are used in the same item.

Experiment 10—Tension Wood in Hardwoods

Objective

To show the difference in anatomy between normal and tension wood in hardwoods.

Material

A hardwood disk or wood specimen with pronounced tension wood. Samples of wood, some with tension wood and some without.

Method

If possible use a disk to illustrate the occurrence of tension wood in a stem, and from samples show the difference in gross appearance of tension wood, as in figure 13. Make cross-section slides of both normal and tension wood. Stain with chlorozinc iodide for the same period of time. (The chlorozinc iodide is a temporary stain. For permanent slides use phloxine and fast green.) Examine both types of slides under the microscope and contrast appearances.

Observation

Note the additional, highly reflective layer on the inside of tension wood cells. There is a lower lignin, and higher cellulose, concentration in tension wood than in normal wood. Tension wood is found on the upper side of leaning hardwood tree stems. It does not occur in softwoods. Compare this with the compression wood in the previous experiment, "Compression Wood in Softwoods," experiment 9.

Application

Tension wood in hardwoods reacts in much the same way as compression wood in conifers. The cells are thicker walled than normal, shrinkage along the grain is greater, but lignin content is lower, and cellulose content is higher. When the wood is machined the fibers tend to pull out, giving a fuzzy surface.

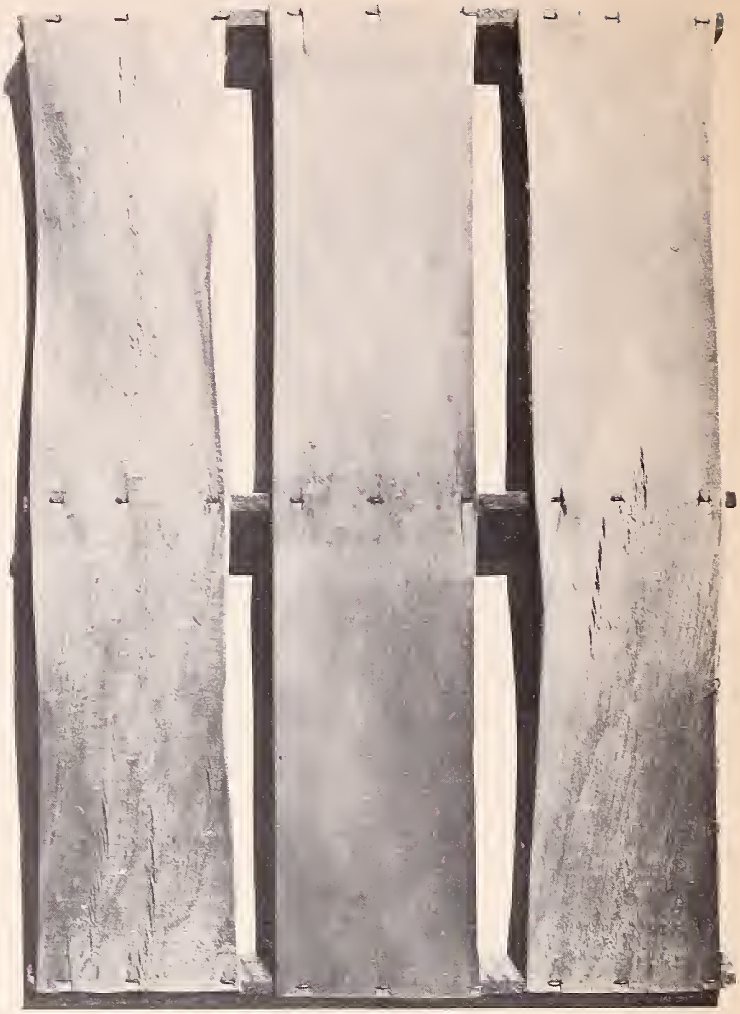
Stains for Tension Wood

Phloxine.—Staining solution

phloxine	1 gram
90 percent alcohol	100 milliliters

Fast green.—Stock solution

fast green	0.5 gram
methyl cellosolve	50 milliliters
absolute alcohol	50 milliliters



M–90,345F

Figure 13.—Top of a berry crate; the two outside pieces contain tension wood but the center does not. Compare the uneven shrinkage and fuzzy appearance of slats with tension wood with the smooth surface of the center slat.

For staining solution, dilute the fast green stock solution with 25 milliliters absolute alcohol and 75 milliliters clove oil.

Staining procedure with phloxine and fast green.—

1. Wash the sections in 95 percent alcohol.
2. Place in phloxine for at least 1 hour.
3. Wash in 95 percent alcohol.
4. Place in fast green for 35 seconds.
5. Wash in 95 percent alcohol.
6. Wash in absolute alcohol.
7. Clear in clove oil for 5 minutes.
8. Wash in toluene.

EFFECTS OF ANATOMY

Experiment 11—Which Way Does the Water Go?

Objective

To show differences in liquid penetration with differences in grain direction.

Material

Blocks of wood, 2 by 2 by ½ inches, with grain parallel to the ½-inch dimension in some, and at right angles to the ½-inch dimension in others, figure 14. A beaker or pan containing colored water (a few drops of dye per quart of water) in which two blocks can float side by side.

Method

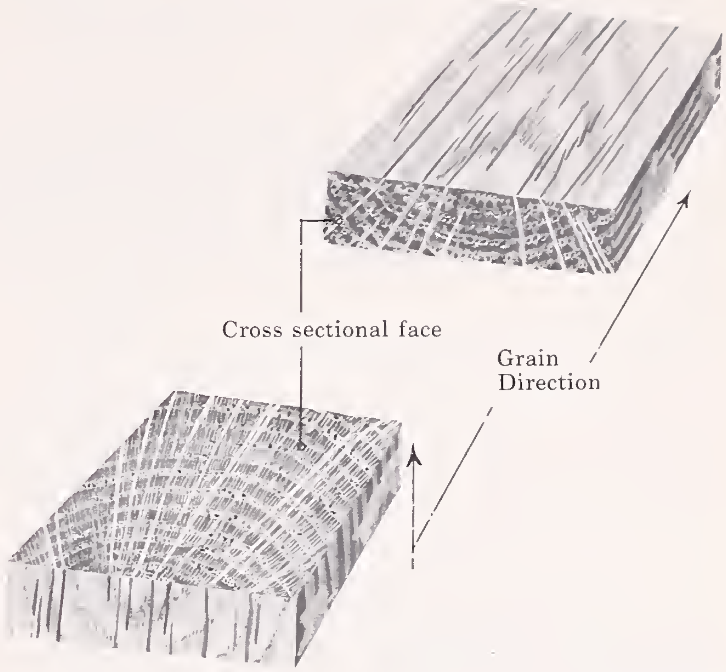
Saw the blocks to the required dimensions and brush free of sawdust, or blow clean with an air blast. Dry the blocks in an oven at 100° to 105° C. for several hours, so that they will absorb moisture readily when placed in the liquid. Place one of each kind of block on the surface of the water.

Observation

The dye will appear first on the upper surface of the block with grain direction parallel to the short dimension. This shows that moisture travels more easily along the grain, that is along the cells, than across it.

Application

When wood is in contact with moisture, exposed end-grain surfaces will absorb moisture most rapidly. Also, when wood is being dried the reverse is true, moisture being lost more rapidly through end-grain surfaces. Thus the ends of a board may split as this part shrinks faster than the rest of the board; therefore, drying must be carefully controlled to reduce splitting, or checking, to a minimum.



M–134,253

Figure 14.—The two types of blocks required in the liquid penetration test. The upper block has the grain at right angles to the small dimension, while the lower block has the grain parallel to the small dimension.

Note: The dimensions of the blocks can be varied depending on how much time is available. Differences between species can be shown by using blocks of different woods.

Experiment 12—Not All Oaks Are Alike

Objective

To show difference in rate of liquid penetration between heartwood of red and white oak.

Material

Blocks of red and white oak heartwood (*not* sapwood), 2 by 2 by ½ inches. Cross-section slides of red and white oak. Beakers large enough to float two blocks and containing colored water.

Method

Prepare the blocks as described in the preceding exercise, but with the grain parallel to the short length in both blocks. Float these blocks in the beaker of water. The water will appear first on the upper surface of the red oak specimen. Examine the slides under the microscope and look for differences in the wood structure between the two species.

Observation

In the microscopical examination, the student should see tyloses blocking vessels in the white oak, but no tyloses in the red oak. Tyloses are formed in vessels when the protoplasm in an adjoining parenchyma cell expands into the vessel and blocks it.

Application

The presence of tyloses makes white oak suitable for tight cooperage, whiskey barrels for example, because the vessels are blocked and leakage is minimized. Red oak, having no vessel blockage, cannot be used for this type of product; it can be used for slack cooperage, such as nail kegs or fish barrels.

Note: The difference in permeability can also be shown by taking pieces of red and white oak, 2 by 2 by 4 inches long, and attempting to blow smoke through them. Smoke can be blown through the red oak but not through the white oak.

Experiment 13—What Happens When Wood Gets Wet?

Objective

To show the difference between tangential and longitudinal shrinkage.

Material

Two dry wooden slats, 1/8 by 2 by 12 inches, cut so that one has the grain running parallel to the long dimension and the other with the grain perpendicular to the long dimension (fig. 15). Waterproof glue, clamps, and spraying device, e.g., two wash bottles.

Method

Dry the two pieces of wood in an oven at 100° C. overnight. As soon as they are removed from the oven, glue the two pieces of wood together on the 2-inch face, using waterproof glue, clamp them and put them back into the oven until the glue sets. Remove from the oven and fix the lower end of the piece in a clamp so that the wood stands upright, figure 16. Soak both sides of the assembly simultaneously. If desired, a semicircular scale can be set behind the wood.

Observation

The assembly will bend away from the side having the tangentially cut slat, as this side expands much more than the portion with the grain parallel to the long axis.

Application

One must understand that different amounts of shrinkage are to be expected along different directions in the same piece of wood. Also, different woods may have different shrinkage capacities. If these points are forgotten the shrinkage force may be sufficient to cause severe warping or split the assembly.

Note: A possible variation is to repeat the experiment with tangentially cut slats of markedly different species, to show shrinkage differences between species. Relate this to the anatomy of the wood seen in "The Three Faces of Wood" and the cell dimensions seen in "What A Single Wood Cell Looks Like."

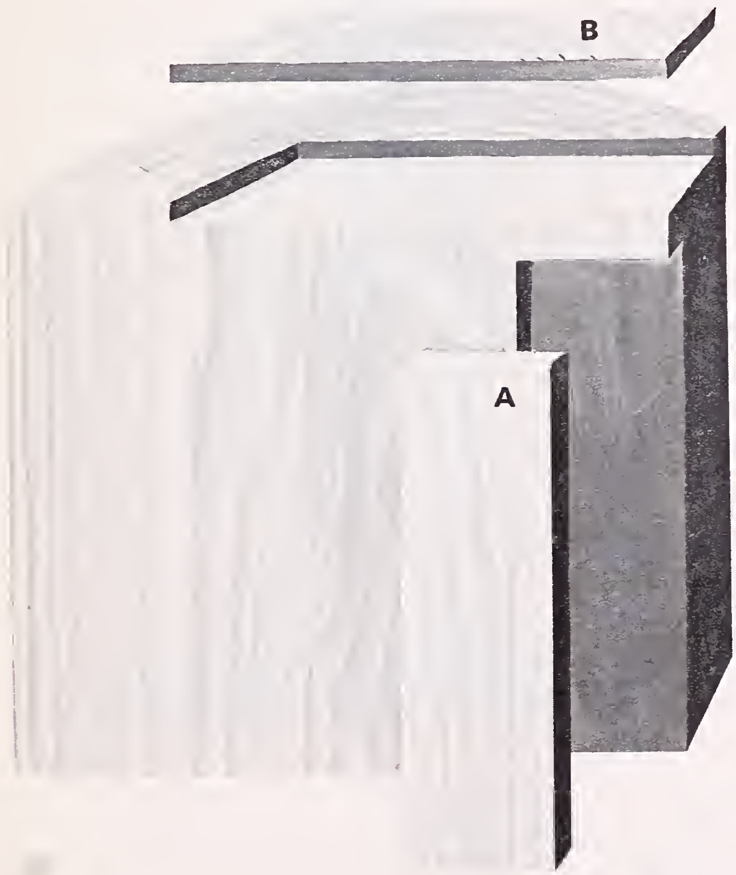


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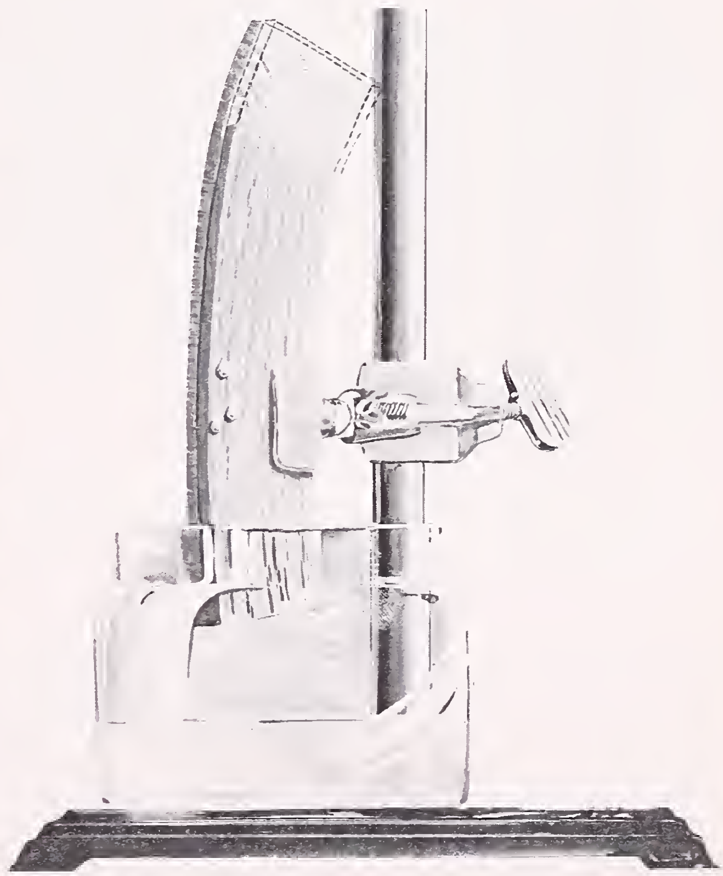
Figure 15.—The slats for the shrinkage test should be cut from a block so that: A, the grain runs parallel to the long dimension, and B, the grain is perpendicular to the long dimension.



M–134,254

Figure 16.—After the glue between the slats has set, the wood specimen should be fixed in a clamp and soaked. (Experiment 13).

Experiment 14—What is Specific Gravity?

Objective

To define specific gravity and to show how it varies among species.

Material

Wood specimens 1 by 1 by 10 inches of white pine, southern pine, oak, and aspen. A 500-cc. graduated cylinder, drying oven, balance, and ruler.

Method

The method used here to determine specific gravity is called the flotation method, because the value is found from the amount of the specimen below the surface when it is floating in a liquid.

First, place the wood samples in an oven at 105° C. overnight to remove excess moisture. Remove each specimen from the oven, weigh it, replace in the oven for about 2 hours and reweigh. Repeat until each specimen reaches a constant weight, indicating that as much moisture as possible has been removed. The sample then is ready to be placed in the cylinder (fig. 17).

A graduated cylinder is suggested, but any vessel in which the sample is forced to float upright can be used. The cylinder should contain enough water to float a specimen with its top above the cylinder. Gently lower the specimen into the water, taking care not to allow it to sink too deeply. When it has reached its floating level, withdraw the specimen from the water and measure the length of the sample which was under water.

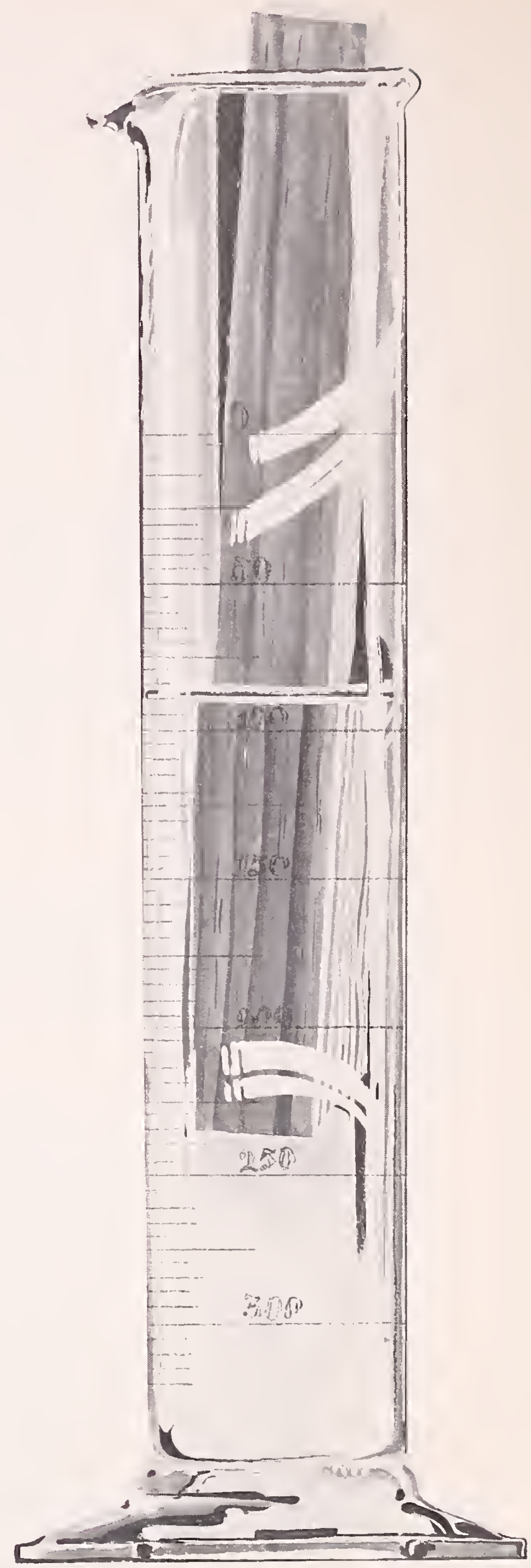
Observation

Specific gravity of an object is obtained by dividing the weight of the object by the weight of an equal volume of liquid.

$$\text{specific gravity} = \frac{\text{weight of object}}{\text{weight of equal volume of water}}$$

Any liquid may be used, but water is the most common.

The concept of specific gravity comes from Archimedes' principle which showed than an object floating in water was being held up by a force equal to the weight of water displaced. If a sample sank to where the surface of the water coincided with the top of the sample, the specific



M–134,259

Figure 17.—A tall glass cylinder is necessary for the specific gravity test, so that the block will float almost upright, giving a water mark at approximately a right angle to the length of the specimen.

gravity would be 1.0. Thus for the sample by our formula,

$$\text{specific gravity} = \frac{10}{10} = 1.0$$

Let us assume that the specimen sinks only 4 inches into the water, that is, the weight of the specimen is supported by the force of 1 by 1 by 4=4 cubic inches of water. Thus, by the formula,

$$\text{specific gravity} = \frac{4.0}{10.0} = 0.4$$

This is the specific gravity of the entire wood, that is, the cell walls and the spaces in the cells. This value varies for different woods because some woods have more air space or more cell wall material than others, as noted in "Why Woods Have Different Properties," experiment 7. The weight, or density, of the cell wall is the same for all woods, about 1.5. While this value is constant, the amount of cell wall material in a definite volume of wood varies considerably.

Application

Because specific gravity is a measure of the amount of cell wall material in wood, it is a useful indicator of strength properties and of suitability for various uses. Heavy woods, such as Douglas-fir, southern pine, or oak, are used for heavy construction, while lighter ones, white pine or aspen for example, are desirable where load bearing is not the prime consideration.

Experiment 15—How Specific Gravity Affects Expansion

Objective

To show the relationship between specific gravity and shrinkage.

Material

A series of 2- by 2- by 1-inch wood blocks, cut with the 1-inch length parallel to the grain and the other two directions being true radial and tangential directions, as shown in figure 18. Dial gage or accurate calipers.

Method

Thoroughly soak the specimens in water. Wipe with damp cloth, weigh, and measure dimensions in radial and tangential direction with dial gage, figure 18. Place specimens in oven and dry at 105° C. until they reach constant weight. Then remeasure. Percentage of radial and tangential shrinkage is calculated as:

Percent shrinkage

$$= \frac{\text{wet dimension} - \text{dry dimension}}{\text{wet dimension}} \times 100$$

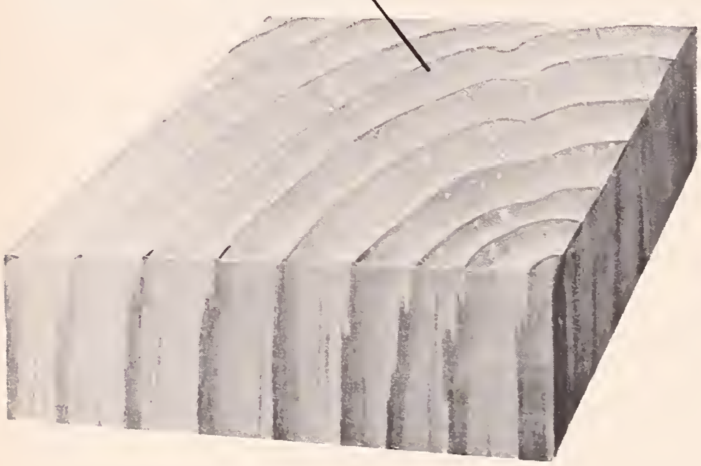
Observation

If a variety of ring widths and species are used throughout the class, results from the group can be compared to show the variation among blocks of the same species, and between blocks of different species.

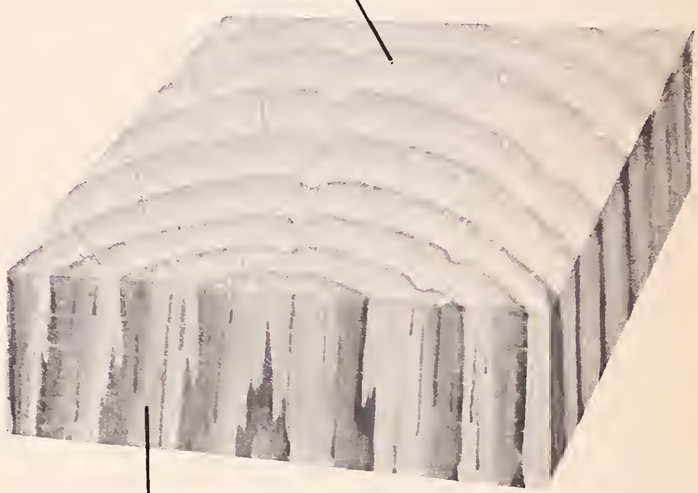
Application

Wood with higher specific gravity tends to shrink and swell more than wood of lower specific gravity. Therefore, when combining different species, or pieces with different specific gravity, in a single product, one must be aware that differences in shrinkage and swelling potential may cause splitting or warping of the piece.

Cross sectional face



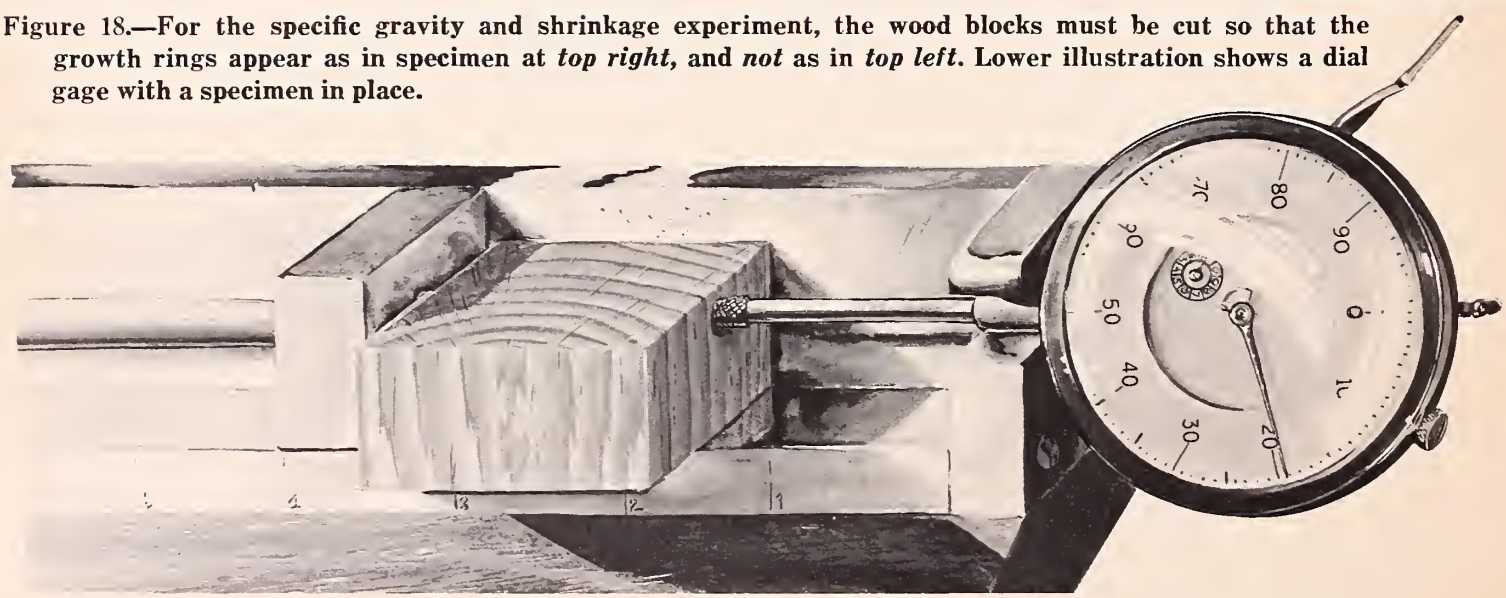
Cross sectional face



Tangential Face

M–134,251, 134,260

Figure 18.—For the specific gravity and shrinkage experiment, the wood blocks must be cut so that the growth rings appear as in specimen at *top right,* and *not* as in *top left.* Lower illustration shows a dial gage with a specimen in place.



Experiment 16—Making Paper

Objective

To show how a sheet of paper is formed.

Material

Blocks of softwood, knife or scalpel, bleach, small heat-resistant jar, and fine wire screen to cover the jar mouth.

Method

Split the blocks of softwood along the grain into toothpick-sized pieces. Place the pieces in the jar, add bleach, and leave in an oven at 50° C. for about 24 hours. Remove the jar from the oven and stir the mixture; if maceration of the wood is not complete, return the jar and contents to oven for a short time. When maceration is complete, allow the fibers to settle, pour off bleach, and wash with water three times.

Fill the jar one-quarter full of water and fit the screen over the jar mouth. Swirl water about to place the fibers in suspension, and invert the jar over a sink. The water will run through the screen leaving the fibers in a mat. When the water has drained off, remove the screen and fibers from the jar and dry them in an oven or over a radiator. When dry, the fiber sheet can be lifted off the screen as a sheet of paper.

Observation

Note that the fibers will interlock and form a woven mat as the water drains off the wood pulp.

Application

In making paper, the wood may be reduced to individual cells by chemically separating the cells, as done here, or grinding them apart mechanically. The fibers are mixed with water and various chemicals, then spread onto a moving screen where the water is removed. The resulting sheet is passed over warm rollers to complete the drying, and may be run through a series of polished rollers to finish the sheet surface.

Experiment 17—How Strong Is a Single Fiber?

Objective

To demonstrate the strength of single fiber.

Material

Macerated cell material from southern pine, as these species have relatively long fibers. Balance, burette, beakers, jewelers chain, dissecting microscope, forceps, glue, heavy paper or card stock.

Method

Using the technique described in the proceding study, macerate the wood. Fibers to be tested are taken with forceps from the maceration while it is under a dissecting microscope.

The fiber, handled at its ends with jewelers' forceps, is placed across the narrow ends of two-wedge-shaped paper tabs held in a bulldog spring paper clamp, figure 19. Each end of the fiber is glued to the tabs by applying a drop of household glue. The fiber assembly is left overnight to harden.

The fiber assembly is attached to two fine jewelers' chains by small hooks inserted through holes in each tab. These chains are then fastened to the tension testing device, as in figure 19, and the spring clamp released. With this arrangement, the fiber is automatically alined in the direction of the applied load.

The testing device consists of a modified analytical balance. One chain of the assembly is attached to one end of the balance arm and the other chain to the balance platform. A 100-milliliter aluminum beaker is attached to the other end of the balance arm and counterbalanced, so that there is no tension on the fiber assembly. Load is applied to the fiber by admitting water to the beaker at a rate of 60 milliliters per minute. The quantity of water admitted at time of break is recorded.

Observation

Note the amount of water required to break the fiber. Thin-walled earlywood and thick-walled latewood fibers can be tested and their relative strengths compared.

Application

The strength of the individual wood cell is important in lumber and in the manufacture of pulp and paper products.

Note: This study is based on work by D. C. McIntosh, The Mead Corporation, Chillicothe, Ohio, and reported in "Chemical Composition and Physical Properties of Wood Fibers. III: Tensile Strength of Individual Fibers from Alkali Extracted Loblolly Pine Holocellulose," by B. Leopold and D. C. McIntosh, *Tappi*, Vol. 44(3): 235–240.

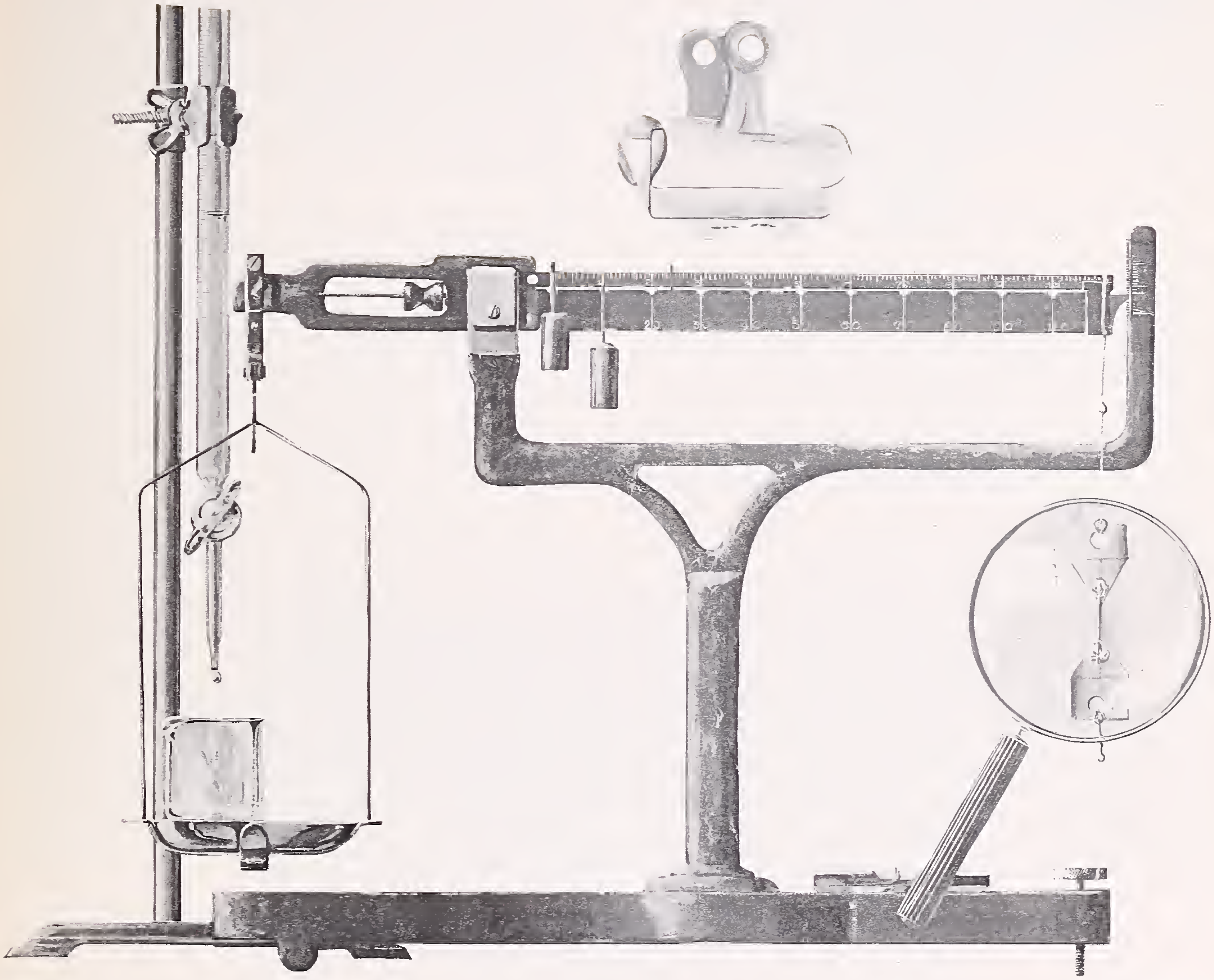


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Figure 19.—Apparatus for testing the strength of a single fiber. In preparation, the fiber is glued to the tabs held in the clamp, as at top of figure.

Experiment 18—Why Use Glue?

Objective

To show differences between nailed and glued wood beams.

Material

Nine strips of softwood (1/4 by 1 by 18 inches), hammer, nails, glue, clamps, two supports, corrugated fiberboard backdrop, and 5000-gram weight.

Method

Take three of the strips and nail them, one on top of the other. Take three others, glue them together, and allow the glue to set.

Place the remaining three strips, one on top of the other, across the supports, put the weight in the middle and mark the level of the bottom of the beam on the backboard (fig. 20).

Replace the three strips with the three nailed together, apply the weight, and mark the bottom of the beam. Do the same with the glued beam.

Observation

The three loose strips bend most, the nailed beam does not bend as far, and the glued beam bends least. In the first case there is little support because the loose strips act as individual pieces. When nailed, there is greater unity, and when glued it is as though a solid piece of wood were used.

Application

Glued beams, or laminated beams as they are called, are strong and can be made very large. Because they are made of many pieces of wood glued together, they can be made in almost any shape or size the engineer may want, while retaining the strength of solid wood.

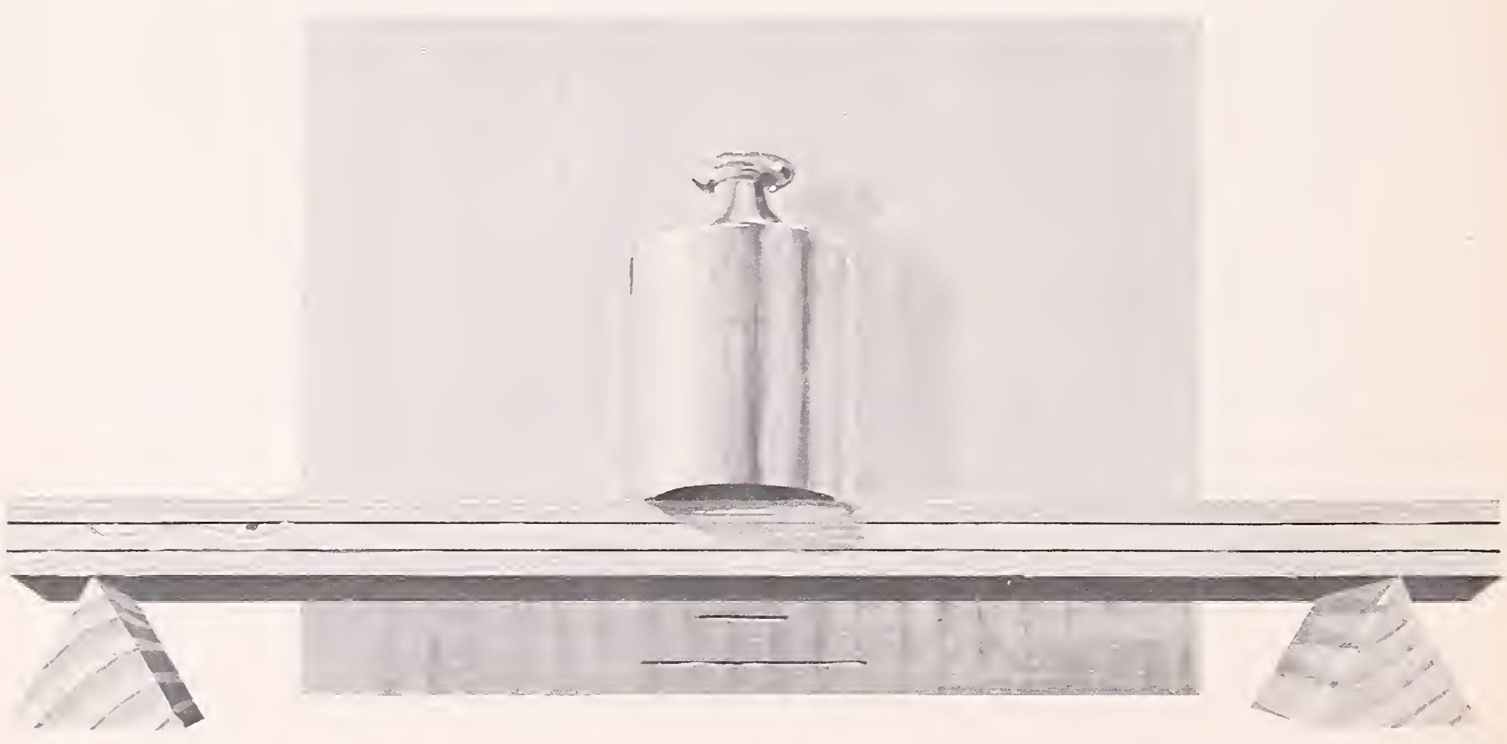

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Figure 20.—The weight is shown on the glued beam. The marks showing the limit of bending for the separate pieces and for the nailed beam are seen below the beam. (Experiment 18).

Experiment 19—Why Use Plywood?

Objective

To show some differences between plywood and solid wood.

Material

Five pieces of oak (1/8 by 3 by 3 inches), two pieces of oak (3 by 3 by 5/8 inches), waterproof glue, clamp, hammer, sharp-pointed nails, basin of water, and calipers or dial gage.

Method

Glue the five thin sheets of oak together with waterproof glue, making sure that the grain directions run at right angles to each other in adjoining sheets, as shown in figure 21. Clamp and allow the plywood to set completely.

1. Hammer nails near the edge of the piece of plywood. Do the same with one of the solid oak pieces.

2. Measure with calipers on a dial gage and note the size of the dry plywood and the solid oak block. Now thoroughly soak both and remeasure. Compare the dimensions before and after wetting for both specimens.

Observation

1. The plywood does not split on nailing, but the solid block does. In the plywood the cells cross each other at right angles in the different layers; when a crack begins, it is stopped by the cells which run across it in the next layer. There is less to stop the cracks developing in the solid block, however.

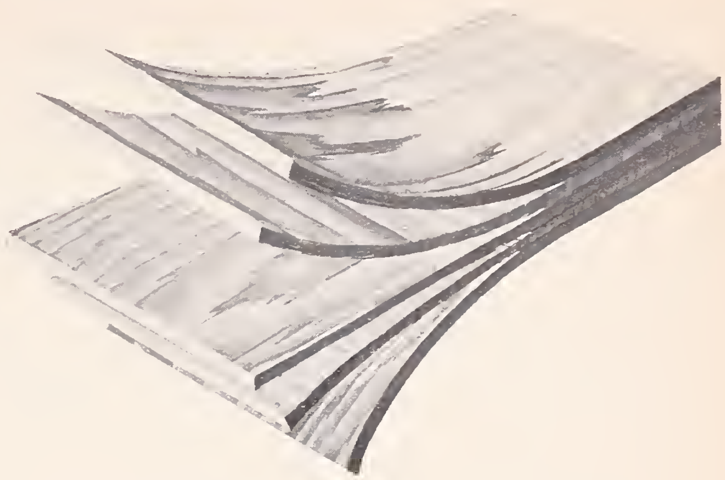

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Figure 21.—Diagram showing alternation of grain direction with each layer in plywood. (Experiment 19.)

2. When soaked, the plywood increases in size less than the solid wood block. Again the cells running at right angles to each other limit the amount of expansion, while there is no such counteracting effect in the solid block.

Application

Plywood is another example of taking wood apart and putting it back together to give a more useful product. The oak plywood holds regular nails better than the solid block, and does not shrink and swell as much. For some purposes this makes it easier to use than solid boards, and also provides larger flat surfaces.

Experiment 20—When to Use a Blunt Nail

Objective

To show effect of wood structure on nailing.

Material

Blocks of white pine and oak (1 by 1 by 7 inches), hammer, and 4-penny common nails, pointed and with points filed dull.

Method

Hammer both types of nails into both types of blocks about 1½ inch from the end of the blocks.

Observation

The softwood, white pine, will not split with either nail. The oak will split with the pointed nail but not with the dulled one.

The softwood cells are relatively long and thin walled. Thus when the pointed nail goes through, the walls break, and the length of the cells prevents a split going far along the grain.

In the hardwood, the cells are shorter, thicker walled, and less flexible than in the softwood. When the pointed nail enters and pushes them apart, they split away from each other, and the split then continues to increase as the nail penetrates. When the blunted nail is hammered in, it crushes the fibers and there is very little pushing apart of the cells; therefore, the wood does not split.

Application

When nailing hardwood, for example, in house trim, it is desirable to use blunt nails, or to bore holes in the wood, to prevent splitting. Since the softwood does not split and is easy to work, it is preferred for much joinery work.

Experiment 2.—Continued from p. 9

Fit the shoots into the stoppers, under water in the pail, then transfer to the bottles as quickly as possible. It is best to hold the bottle over the pail. Support the shoots on ring stands with burette clamps. Leave the apparatus on the bench area in the greenhouse, or in front of a window.

After 3 days, reweigh the bottles, again without stopper, and measure the volume of water in each bottle. Record any changes in weight or volume of water for each bottle.

Observation

Note the reduction in the amount of water in the bottles and the difference in uptake between the stems without wood and those without bark. The exercise shows, in a general way, the principal pathway of water movement in woody stems.

Note: This study is based on material in a Botany Laboratory Manual by permission of P. B. Kaufman, Department of Botany, University of Michigan, Ann Arbor, Mich.

GLOSSARY

annual ring
: The layer of wood, consisting of many cells, formed around a tree stem during a single growing season. It is seen most easily in cross section.

bark
: All the material on the outside of the cambium, and formed by the cambium.

cambium
: The layer of actively dividing cells which produces wood cells on the side toward the pith, and bark cells on the side away from the pith.

cell cavity
: The space enclosed by the cell wall and containing the protoplasm of the living cell.

cell wall
: The membrane forming the cell boundary and which consists of:
  - primary wall—The first cell wall of the enlarging and differentiating cell.
  - secondary wall—The part of the cell wall laid down inside the primary wall after cell enlargement has stopped.

cellulose
: A complex carbohydrate composed of long, unbranched molecules, which makes up 40 to 55 percent by weight of the cell wall substance. It is soluble in acid, but not in alkali.

compression wood
: Wood formed typically on the lower side of branches and stems of leaning or crooked softwood trees. It is characterized by tracheids which are rounded in cross section, have spiral checks in the walls, and a higher than normal amount of lignin in the cell wall. Compression wood is denser and darker than the surrounding wood.

cross section
: The wood surface exposed when a tree stem is cut horizontally and the majority of the cells are cut transversely.

diffuse porous
: Wood of hardwood species in which the vessel diameter remains approximately constant throughout the annual ring.

earlywood
: The less dense part of the growth ring. It is made up of cells having thinner walls, a greater radial diameter, and shorter length than those formed later in the year.

extractives
: Any of several low molecular-weight substances, such as resins, tannins, or alkaloids, which can be removed from wood by extracting with a suitable solvent. They amount to 2 to 15 percent by weight of the wood substance.

fiber
: A general term used for any long, narrow cell of wood or bark, other than vessels or parenchyma. The wood fibers include both the tracheids of softwoods and the fibers of hardwoods.

fibril
: A threadlike strand made up of groups of long-chain cellulose molecules in the cell wall and visible with the microscope.

figure
: Any design or distinctive markings that appear on the surface of a piece of wood.

gelatinous fiber
: A fiber with a relatively unlignified inner wall which is found only in the tension wood of hardwoods.

grain direction
: Direction parallel to the long axis of the majority of cells in a piece of wood.

growth sheath
: The layer of wood laid down over an entire stem and branches during a single growing season, and consisting of both earlywood and latewood.

hardwood
: Wood from a broadleaved tree and characterized by the presence of vessels, e.g., oak, ash, or birch.

heartwood
: The inner part of the stem which, in the growing tree, no longer contains living cells. It is generally darker than sapwood, though the boundary is not always distinct.

hemicelluloses
: Low molecular-weight polysaccharides found in association with cellulose in plant cell walls. They amount to 15 to 25 percent by weight of the wood substance and, unlike cellulose, are soluble in alkali.

latewood
: The denser part of the growth ring. It is made up of cells having thicker walls, smaller radial diameter, and generally longer than those formed earlier in the growing season.

lignin
: An amorphous substance which infiltrates and surrounds the cellulose strands in wood, binding them together to give a strong mechanical structure. It amounts to 15 to 30 percent by weight of the wood substance.

macerate
: To dissolve out the bonding material between plant cells to obtain separate, entire cells.

parenchyma
: Tissue composed of cells which are usually brick-shaped, have simple pits, and frequently, only a primary wall. They are mainly concerned with storage and distribution of food material.

perforation plate
: The wall area with a series of openings between the ends of two vessel elements.

pit
: A recess in the secondary wall of a cell.

pit, bordered
: A pit in which the secondary cell wall partially overhangs the pit membrane.

pit, half-bordered
: A pair of pits in adjacent cells, one pit being simple and the other bordered.

pit, simple
: A pit in which the secondary cell wall does not overhang the pit membrane.

pit aperture
: The opening or entrance leading from the cell cavity into the pit chamber.

pit chamber
: The space between the pit membrane and the overhanging pit border.

pit membrane
: The intercellular layer and primary wall of two adjoining cells forming the external limit of the pit.

pith
: The central core of a stem, consisting mainly of parenchyma or soft tissue.

plywood
: A series of thin layers of wood glued together to form a solid sheet. The grain direction runs at right angles in adjacent layers.

polysaccharides
: Carbohydrates, such as starch or cellulose, decomposable into two or more molecules of monosaccharides (simple sugars like glucose), or their derivatives.

radial face
: The wood surface exposed when a stem is cut along a radius from pith to bark, and the cut is parallel to the long axis of the majority of the cells.

ray
: A ribbonlike group of cells, usually parenchyma, extending radially in the wood and bark.

ray, fursiform
: A ray which is spindle-shaped when seen on the tangential wood face, and especially rays containing resin ducts in conifers.

resin duct
: A space in which resin has accumulated between the cells.

ring porous
: Wood of a hardwood species in which the vessel diameter is considerably larger in the earlywood than in the latewood.

sapwood
: Wood immediately inside the cambium of the living tree, containing living cells and reserve materials, and in which most of the upward water movement takes place.

softwood
: Wood from a coniferous, or cone-bearing tree, and characterized by the absence of vessels, e.g., fir, pine, spruce.

specific gravity
: The ratio of the weight of a piece of wood in air to the weight of an equal volume of water. As wood shrinks and swells depending on the moisture content, the moisture content of the wood must be specified to determine the volume.

tangential face
: The wood surface exposed when a cut is made at right angles to the rays and parallel to the long axis of the majority of cells.

tension wood
: Wood formed typically on the upper side of branches and stems of leaning or crooked hardwood trees. It is characterized by reduced lignin in the cell wall and often by the presence of an internal gelatinous layer in the fibers.

torus
: Thickened central portion of the pit membrane in the bordered or half-bordered pit of a softwood.

tracheid
: A long narrow wood cell, the only openings in which are pits. Compare with a vessel element.

tyloses
: An expansion of a parenchyma cell through a pit into a neighboring vessel; the tyloses may fill the invaded cell cavity partially or completely, reducing or preventing passage of liquids or gases.

veneer
: A thin slice of wood cut with a knife or saw from a log.

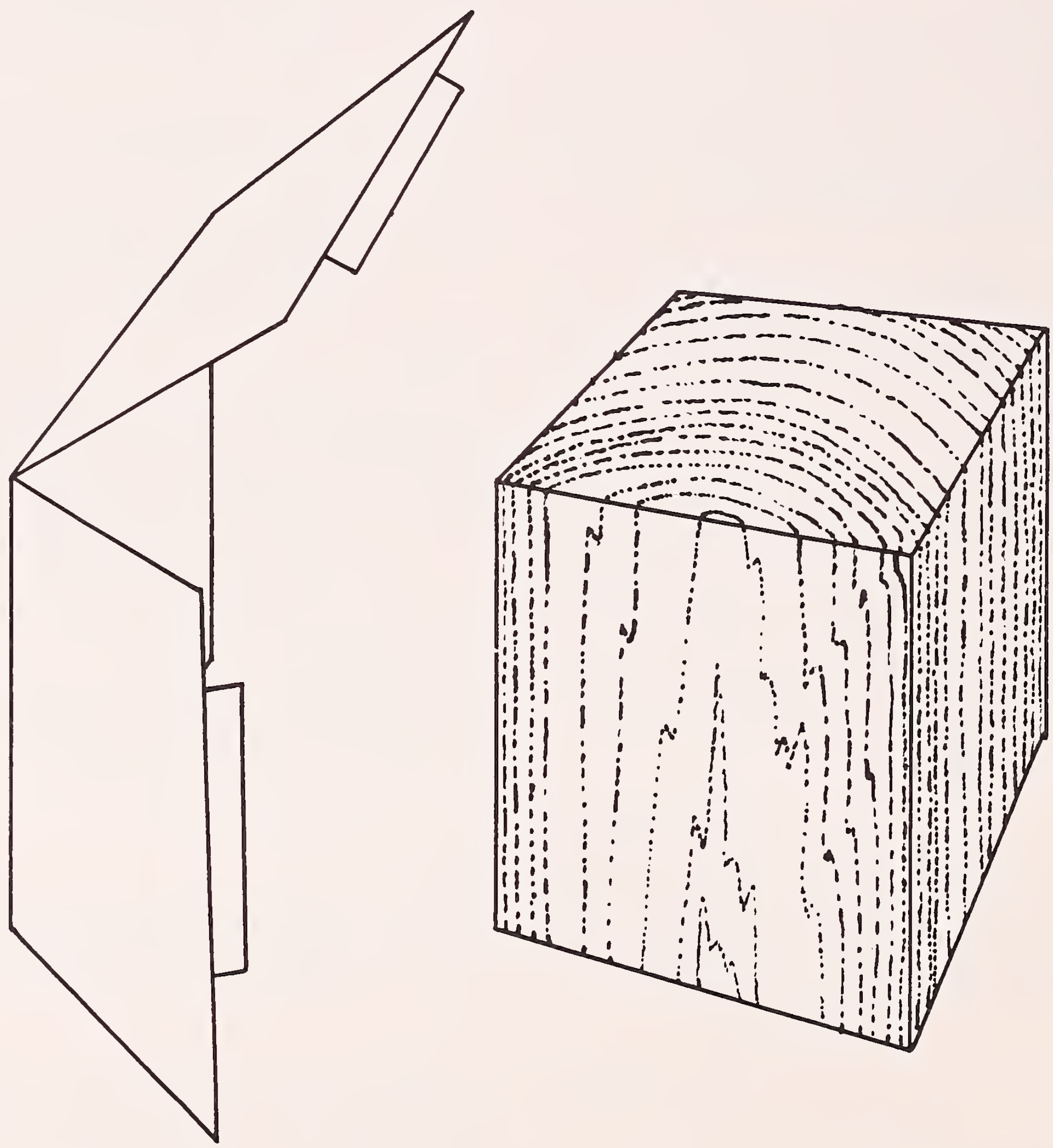
vessel
: A series of cells extending longitudinally in the stem, the ends of the cells having fused together to form a long tube.

vessel element
: One of the cells forming a vessel, having pits in the walls and a perforation plate where it joins another vessel element.

xylem
: That portion of the stem, branches, and roots between the pith and the cambium; the wood.

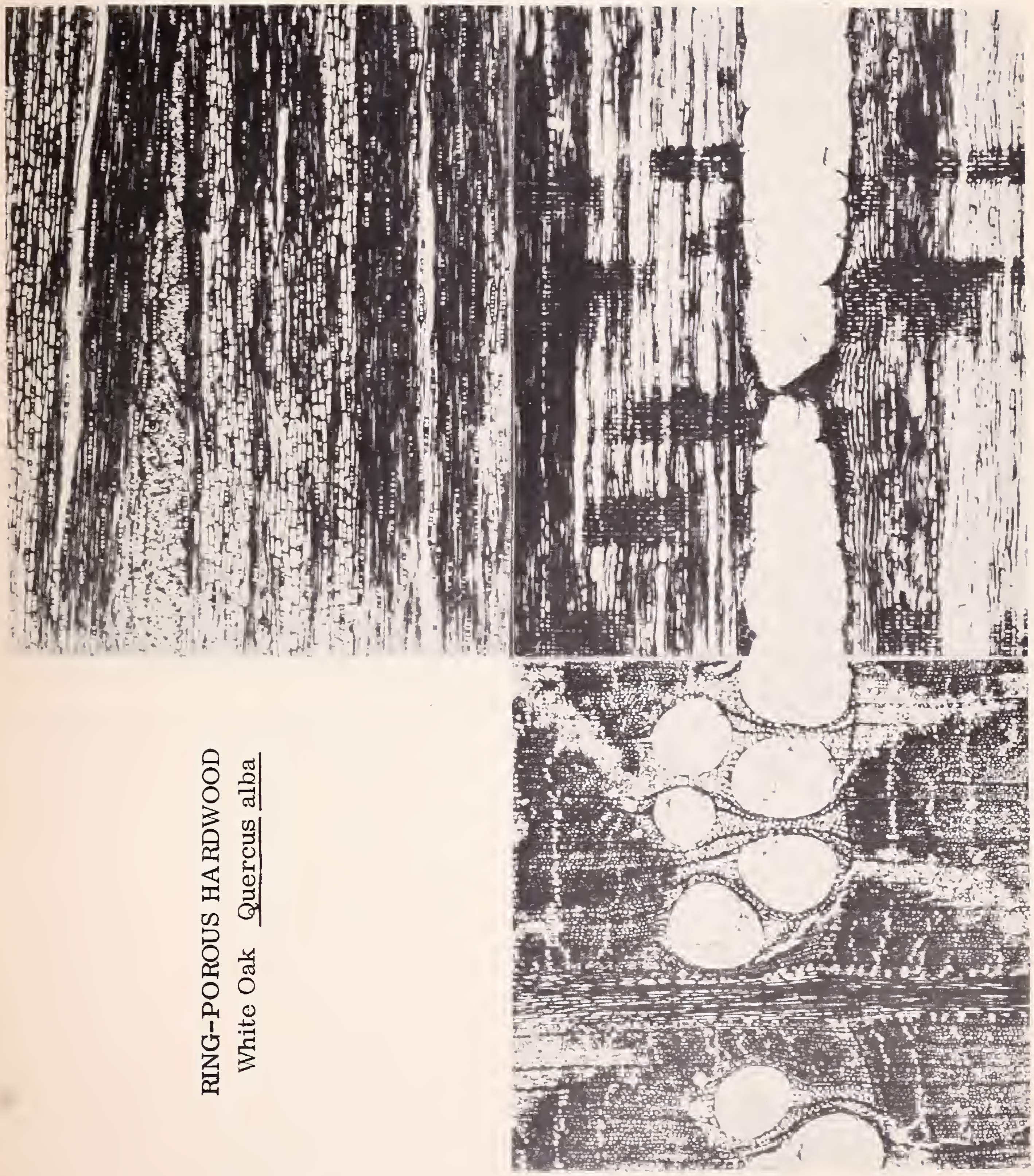
PHOTOGRAPHS OF WOOD STRUCTURE

To obtain a three-dimensional impression of the structure of a wood block, the photographs on the following pages, fig. 22 (M–134249), fig. 23 (M–134247), fig. 24 (M–134248), fig. 25 (M–134250), may be cut out and glued to three sides of a 3⅛- by 3⅛- by 3⅞-inch wood block as shown in the following sketch, fig. 26 (M–134266).



M–134,266

Tangential Face   Radial Face



Direction of Growth

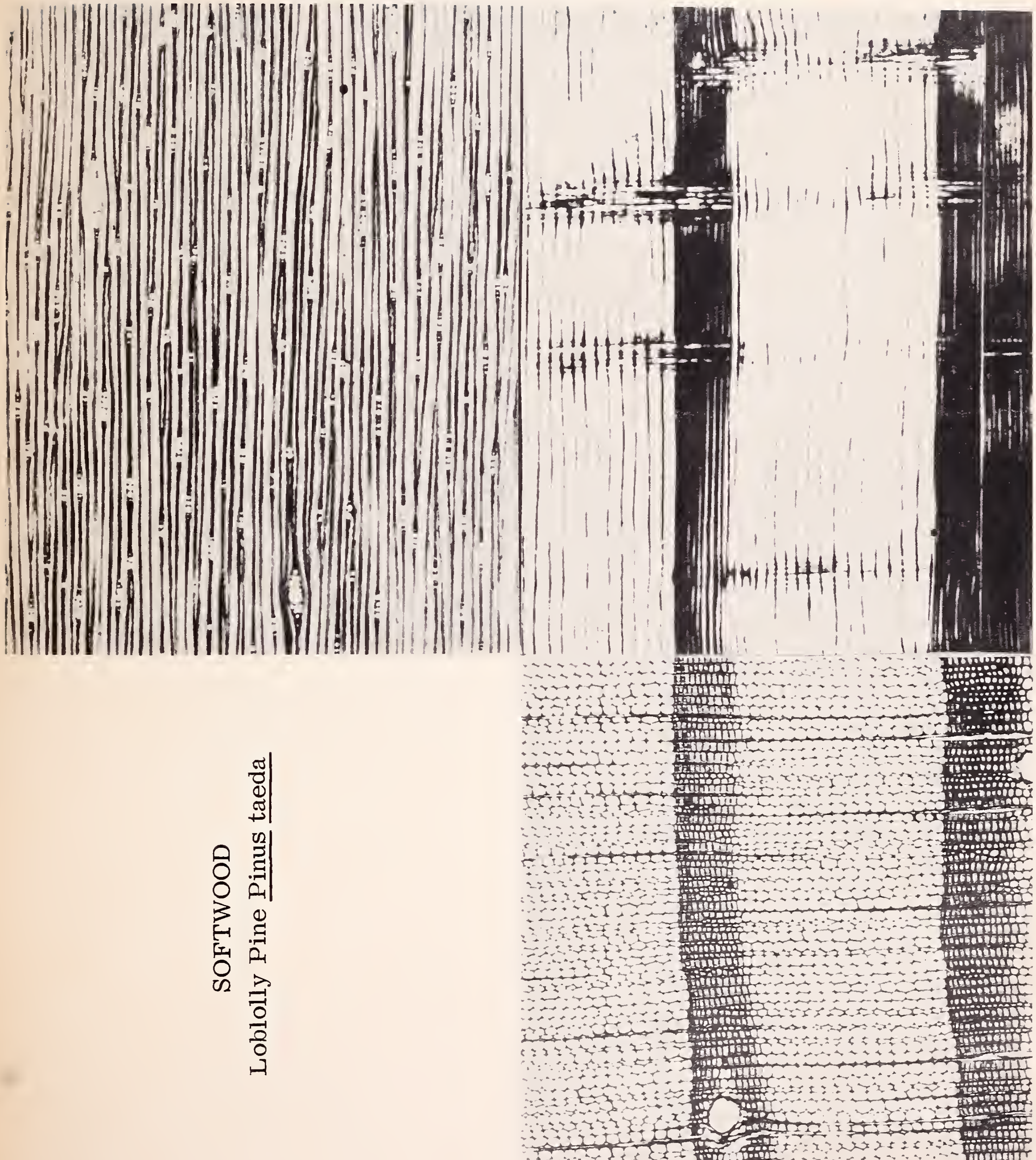
RING-POROUS HARDWOOD

White Oak *Quercus alba*

M–134,249

Tangential Face

Radial Face



Direction of Growth

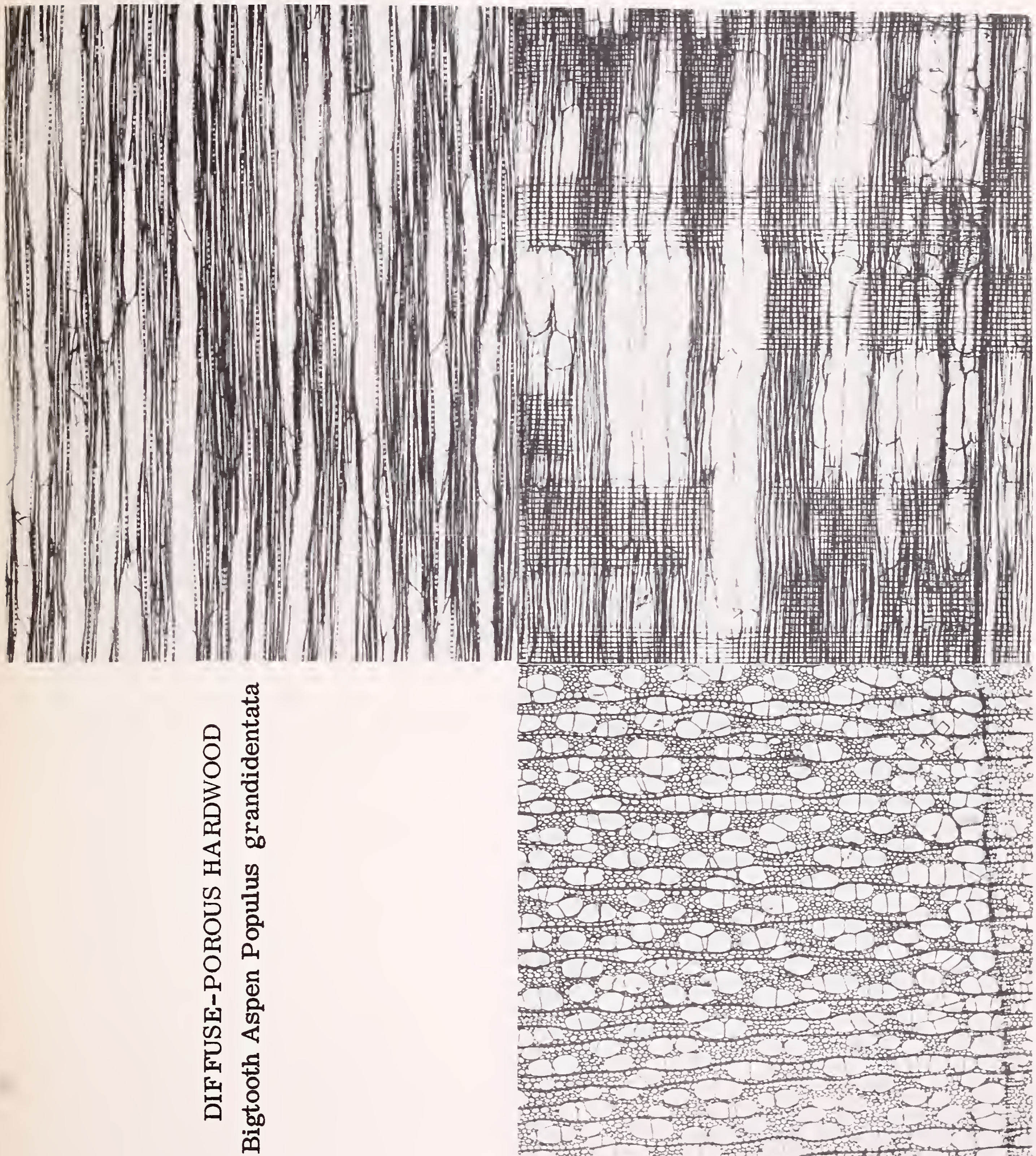
M–134,247

SOFTWOOD

Loblolly Pine *Pinus taeda*

Tangential Face

Radial Face



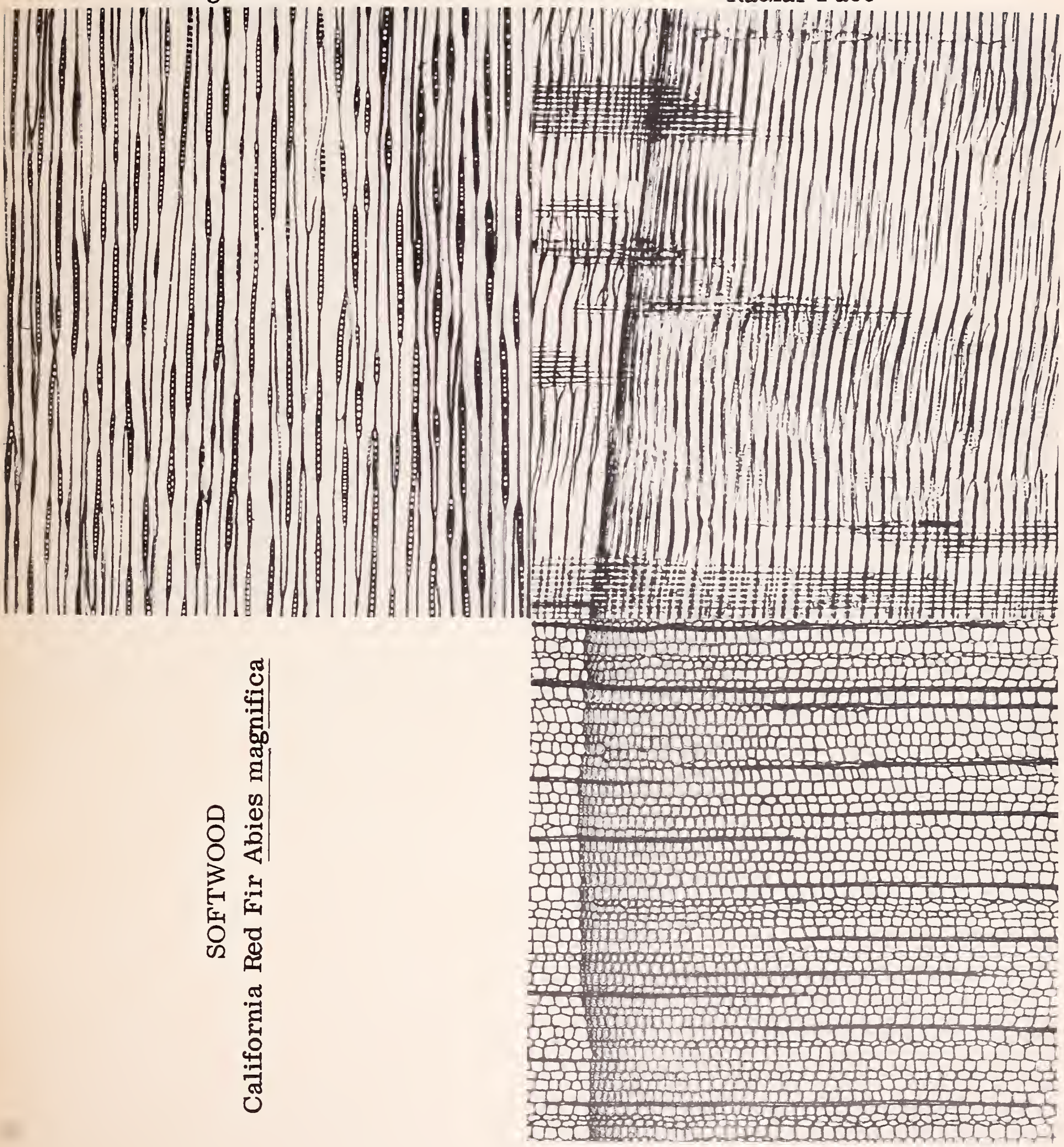
DIFFUSE-POROUS HARDWOOD

Bigtooth Aspen Populus grandidentata

Direction of Growth

M–134,248

Tangential Face   Radial Face



Direction of Growth

SOFTWOOD
California Red Fir *Abies magnifica*

M–134,250

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